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Silver

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[54] METHOD AND APPARATUS FOR LOCATING PATTERNS IN AN OPTICAL IMAGE

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[73] Assignee: **Cognex Corporation**, Natick, Mass.

[21] Appl. No.: **240,079**

[22] Filed: **May 9, 1994**

Related U.S. Application Data

[63] Continuation of Ser. No. 828,241, Jan. 30, 1992, abandoned.

[51] Int. Cl.[6] **G06K 9/20**

[52] U.S. Cl. **382/202**; 382/151

[58] **Field of Search** 382/48, 8, 18, 382/53, 141, 145, 151, 194, 192, 282, 273; 348/135; 356/400, 401; 250/561

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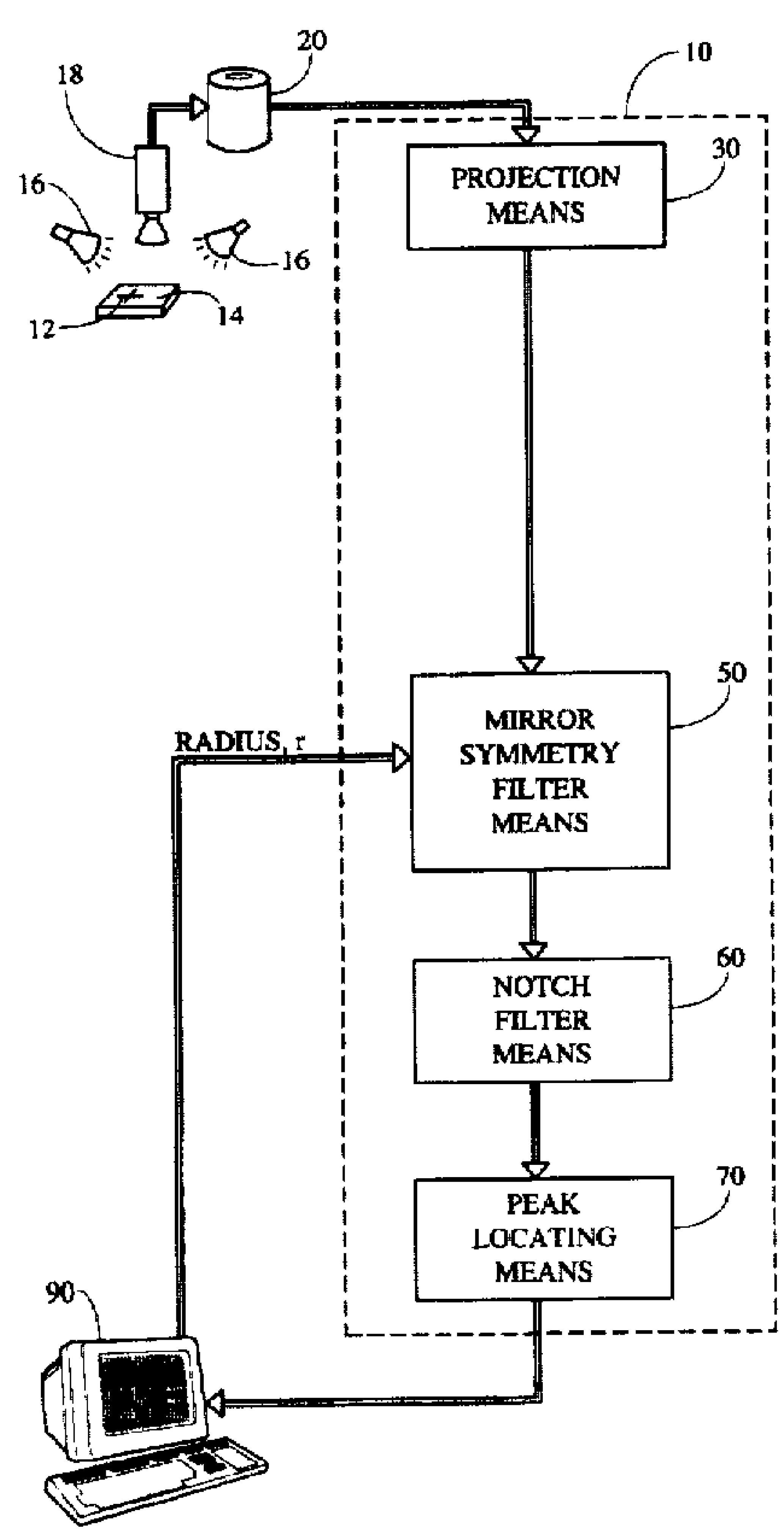
[57] **ABSTRACT**

The invention provides methods and apparatus for processing an image to identify the position of a linear pattern—for example, a line or a cross-hair comprising a plurality of intersecting lines. The system performs a first processing step for generating a projection of the image along axes aligned with an expected position of the linear patterns. A second processing step performs a mirror symmetry filtering on the projection to bring out a single peak corresponding to the center of the linear pattern. To further isolate that peak, the system performs a further filtering operation to remove peaks of lesser slope angle, so that only a highly sloped spike corresponding to the linear pattern will remain. The position of the center that peak corresponds to the center of the linear pattern in the original input signal.

16 Claims, 6 Drawing Sheets



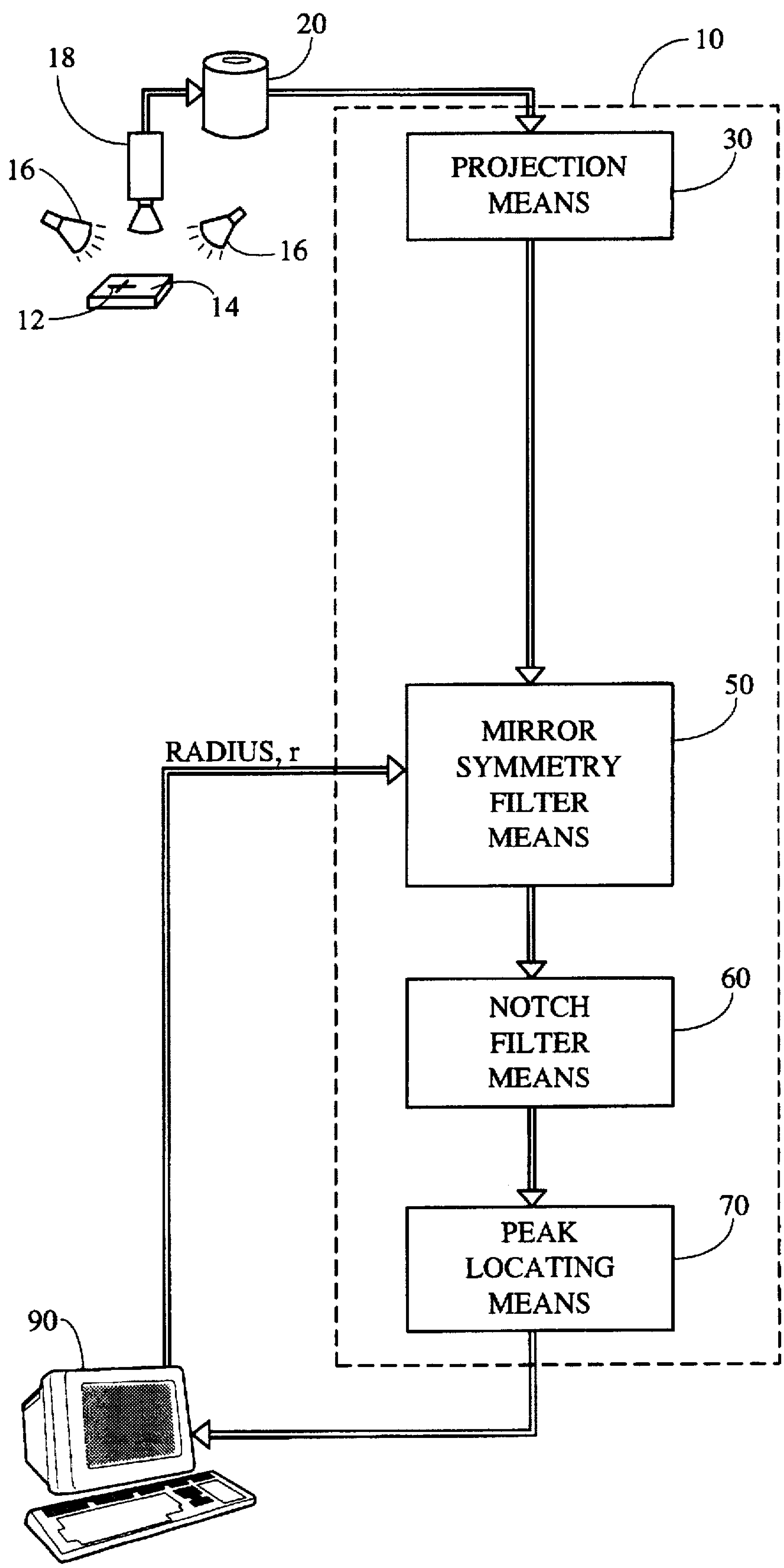

20
18
10
30
PROJECTION MEANS
16
16
12
14
50
MIRROR SYMMETRY FILTER MEANS
RADIUS, r
60
NOTCH FILTER MEANS
70
PEAK LOCATING MEANS
90

FIG 1

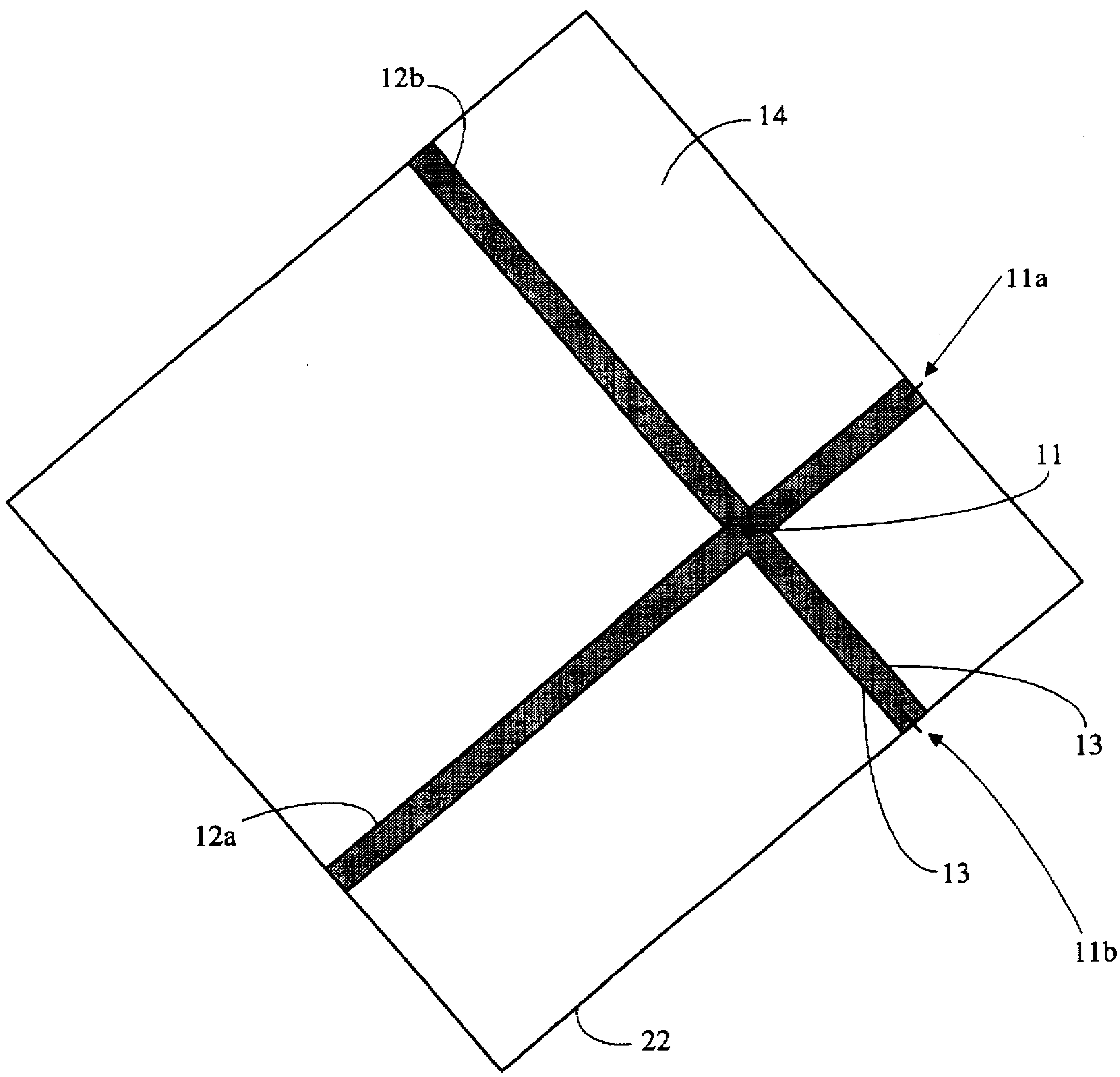


FIG 2

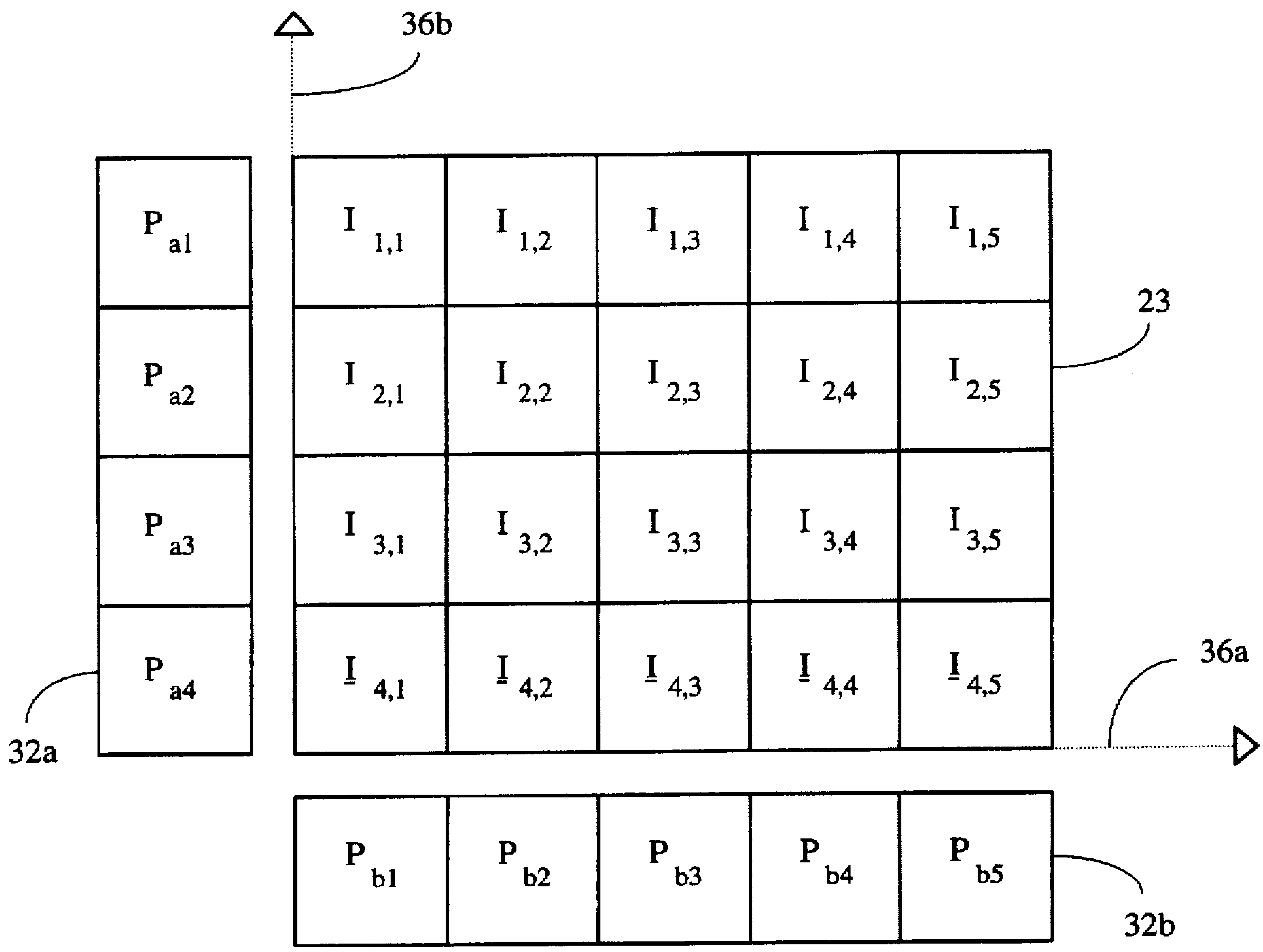

36b
P_{a1}
P_{a2}
P_{a3}
P_{a4}
$I_{1,1}$ $I_{1,2}$ $I_{1,3}$ $I_{1,4}$ $I_{1,5}$
$I_{2,1}$ $I_{2,2}$ $I_{2,3}$ $I_{2,4}$ $I_{2,5}$
$I_{3,1}$ $I_{3,2}$ $I_{3,3}$ $I_{3,4}$ $I_{3,5}$
$I_{4,1}$ $I_{4,2}$ $I_{4,3}$ $I_{4,4}$ $I_{4,5}$
23
36a
32a
P_{b1} P_{b2} P_{b3} P_{b4} P_{b5}
32b

FIG 3

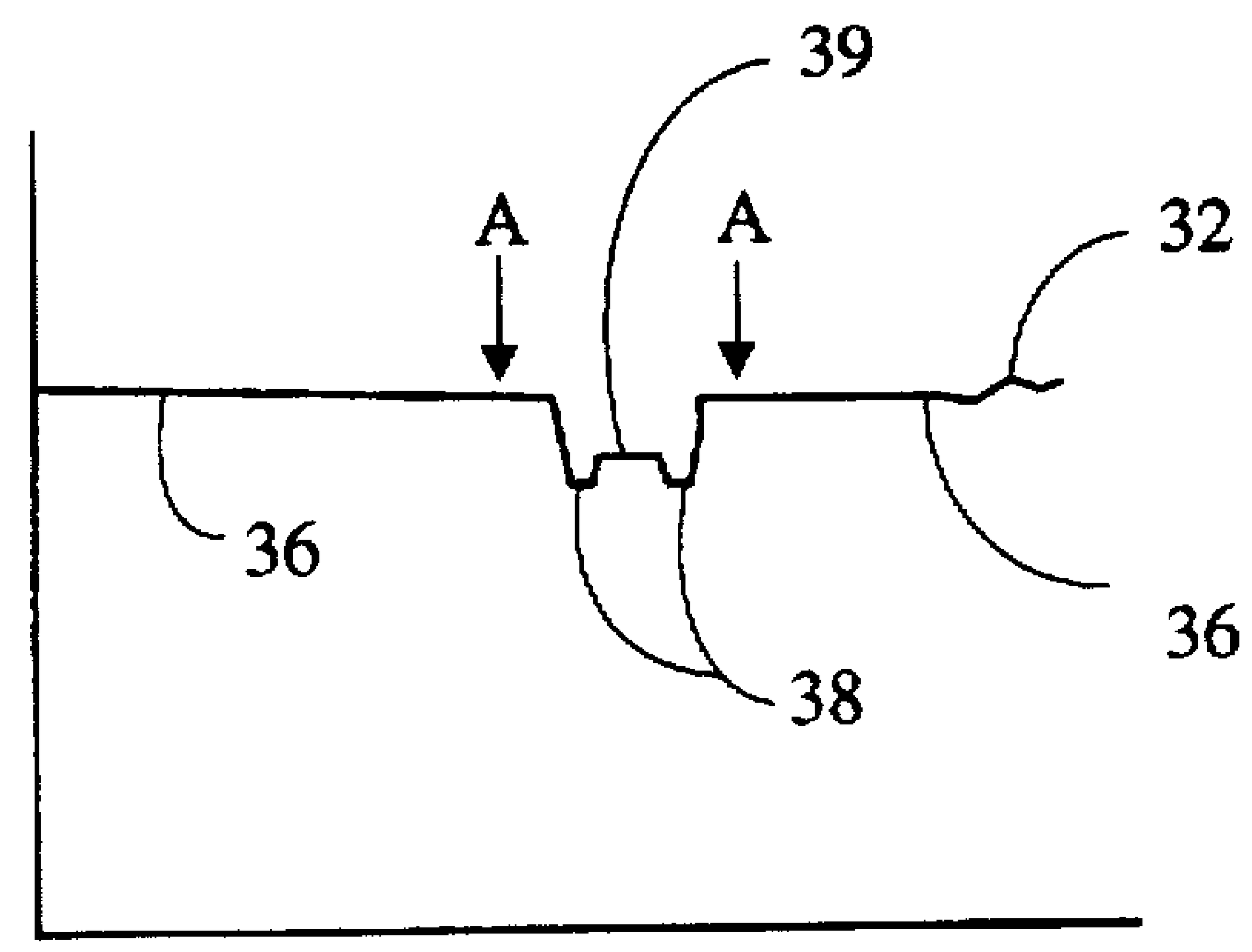


FIG 4A

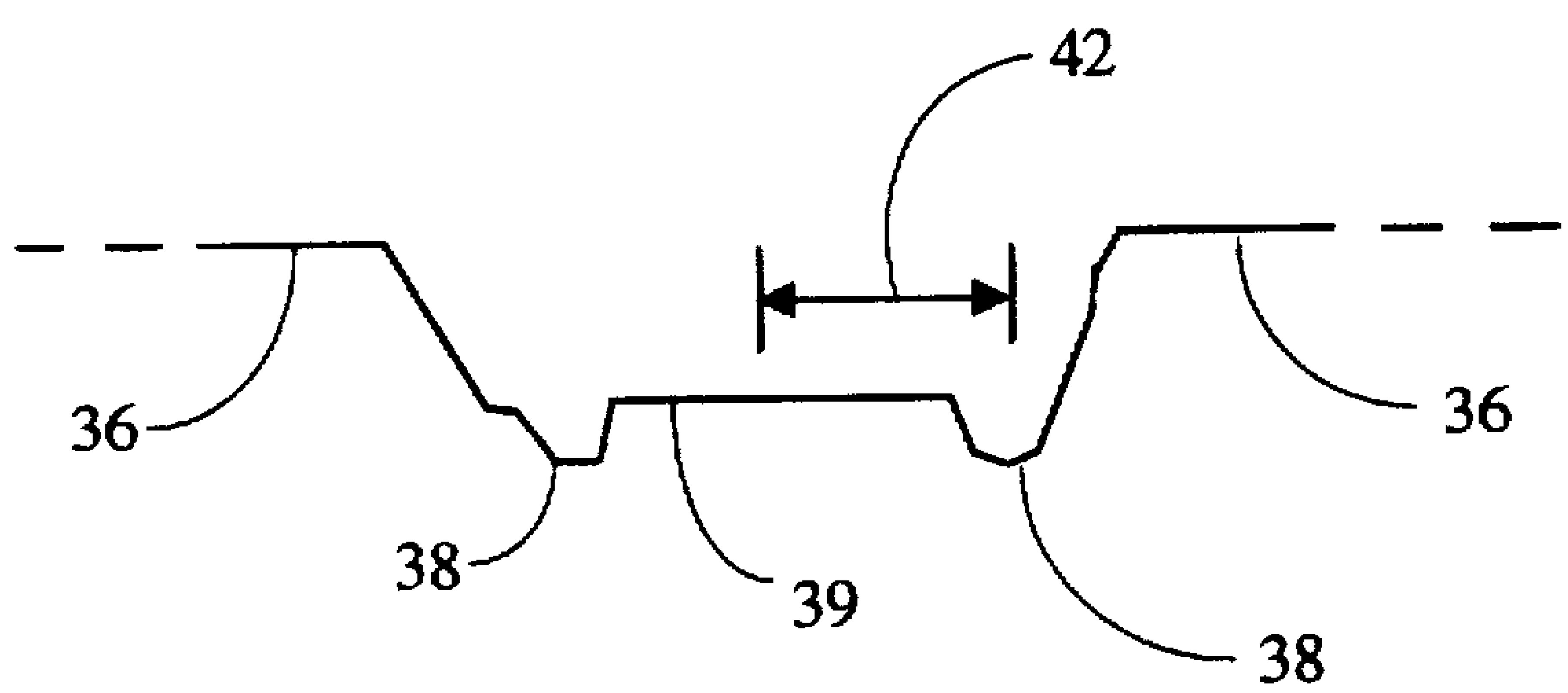


FIG 4B

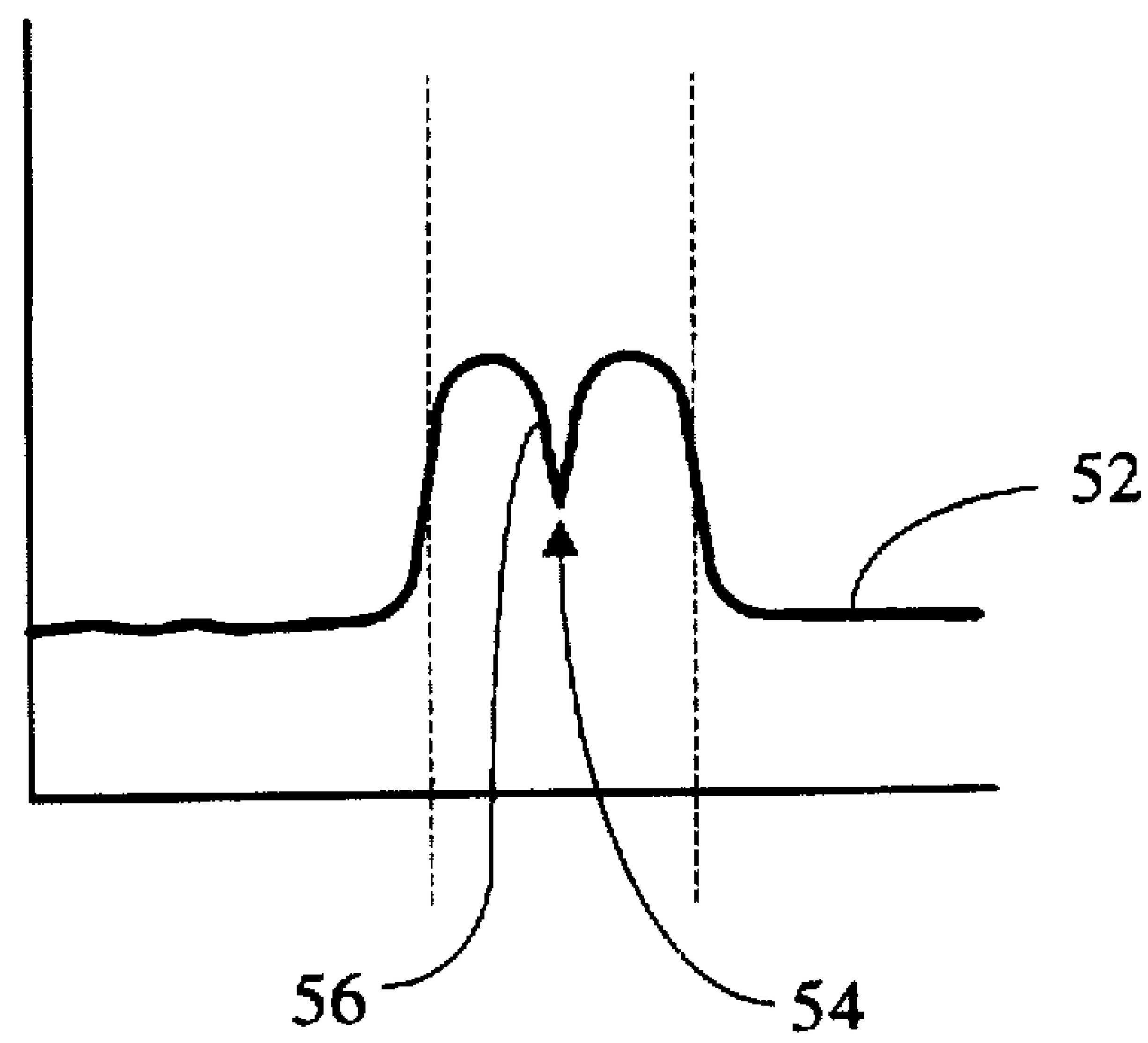


FIG 4C

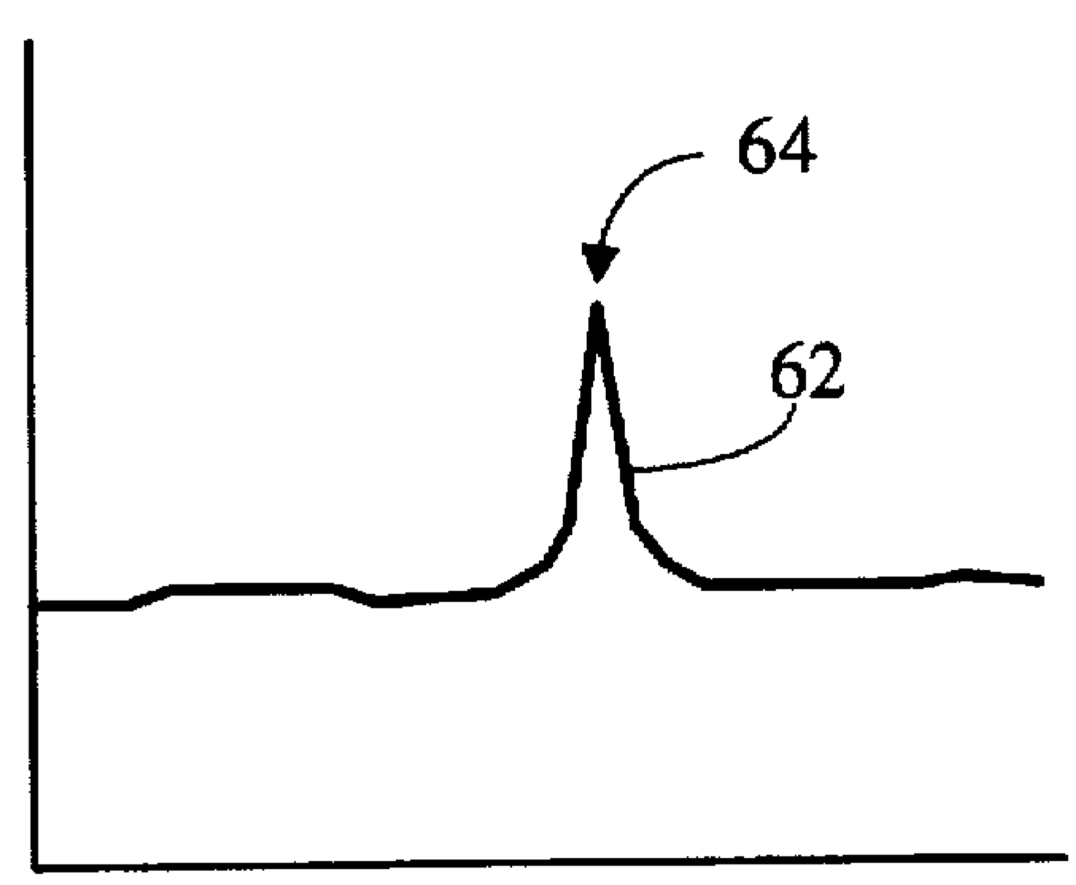


FIG 4D

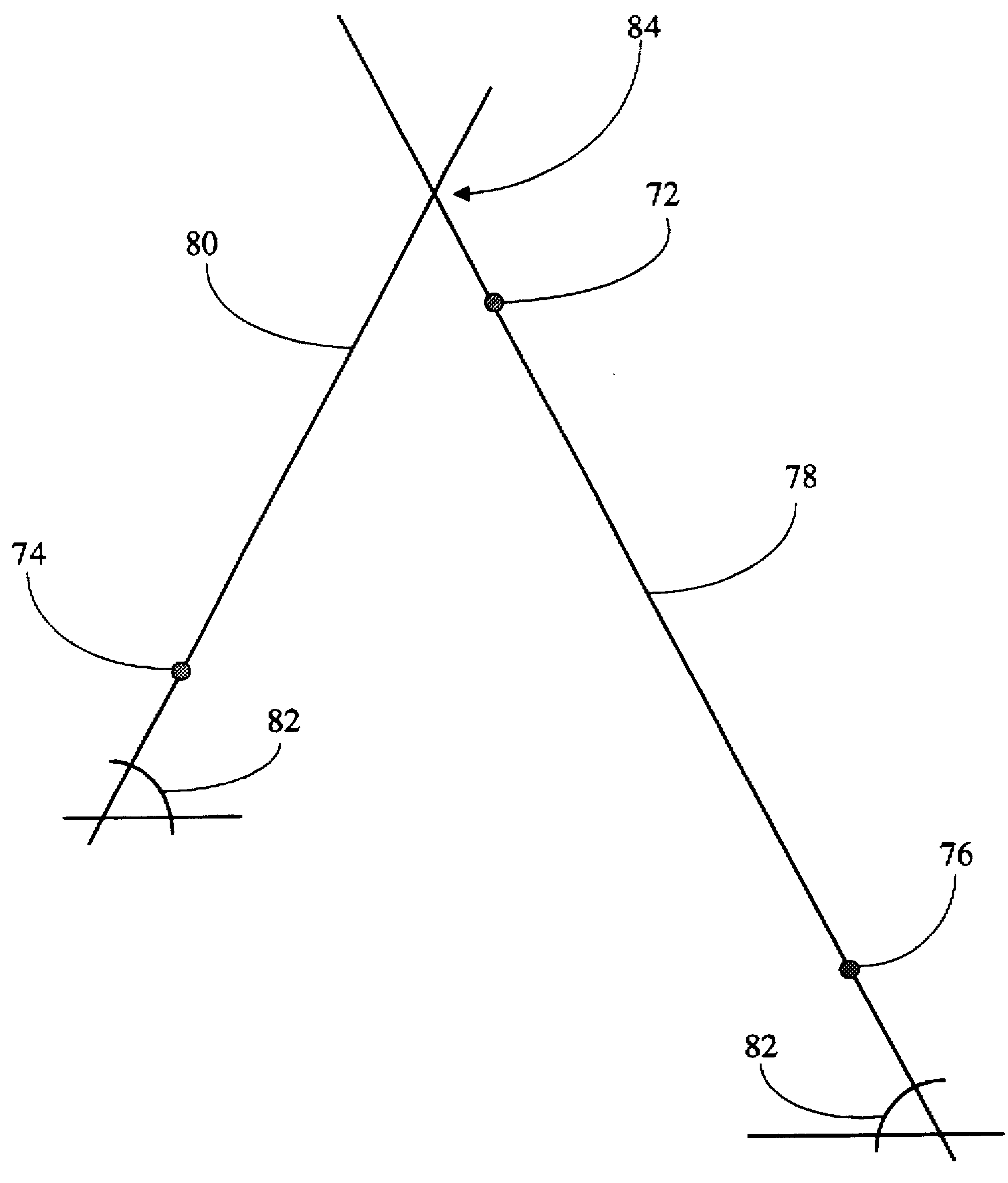


FIG 5

METHOD AND APPARATUS FOR LOCATING PATTERNS IN AN OPTICAL IMAGE

This application is a continuation of U.S. patent application Ser. No. 07/828,241 filed on Jan. 30, 1992, now abandoned, for "Method and Apparatus for Locating Patterns in an Optical-Image", the contents of which are hereby expressly incorporated.

FIELD OF THE INVENTION

This invention relates to machine vision, and more particularly, to methods and apparatus for accurately locating linear patterns, e.g., a cross-hairs, in an optical image.

BACKGROUND

Automated product assembly and manufacturing processes often rely on machine vision to determine the position of a component being processed. Typically, a linear pattern, such as a cross-hair, is used as a reference point for precision alignment.

Various methods of machine vision positioning are currently practiced. Among the primary ones are variations on the general Hough transform and correlation (template matching). With respect to the latter, there exists binary exclusive-OR correlation and, more recently, gray-scale normalized correlation. One common element of these prior art methods is that they require, as input, an image template of the pattern they are to locate.

As a component undergoes various stages of assembly or manufacture, the appearance of the alignment pattern may change. For example, etching and masking of a semiconductor wafer can alter the contrast, definition and thickness of cross-hairs embedded in the wafer. Thus, in order to be effective during the entire assembly process, the prior art methods typically require many image templates. Unfortunately, the actual appearance of a locating pattern on a component is not always predictable, frustrating even the use of multiple ideal template images.

A further drawback of prior art systems is that they consume excessive time in comparing actual optical images to the multiple template images.

In view of the foregoing, an object of the invention is to provide an improved vision system and, more particularly, improved methods and apparatus for accurately locating the center of a linear pattern, e.g., a line or a cross-hair, in an optical image.

Still another object of the invention is to provide a machine vision positioning system that does not rely on an object template in order to position a piece.

Yet another object of the invention is to provide a system capable of positioning a component notwithstanding changes in its appearance during processing.

SUMMARY OF THE INVENTION

The aforementioned objects are attained by the invention, which provides machine vision methods and apparatus capable of quickly and accurately locating linear patterns, such as lines, or cross-hairs made up of intersecting lines, on a component.

In one aspect, the invention provides an apparatus for processing a component image to identify the position of a linear pattern thereon. The apparatus includes a first processing element for generating a projection of the image along an axis substantially aligned with an expected orientation of the linear pattern. As described further below, a projection is essentially a one-dimensional "profile" of the input image.

If a linear pattern in the image is aligned with the projection axis, edges of that pattern will correspond with peaks on an otherwise flat, or substantially flat, profile. An apparatus according to the invention further includes a processing element for performing "mirror symmetry" filtering on the projection. That filtering relies on the symmetry of the edge peaks to bring out a single peak corresponding to the center of the linear pattern.

To isolate that center peak, the apparatus includes a notch detection element that operates on the mirror symmetry filter output to filter out lesser peaks of low slope angle, so that only a highly sloped spike corresponding to the linear pattern of interest will remain.

The center of that peak corresponds to the center of the linear pattern in the original input signal. The apparatus, accordingly, includes a peak finding element that determines the location of the peak center. To improve accuracy of that determination, the apparatus can interpolate a peak position from the apparent peak and the two neighboring points on opposite sides of that apparent peak.

An apparatus of the type described above can determine the location of a line in an input image, e.g., a "street" in a semiconductor wafer. Alternatively, it can to locate a single "hair" of a cross-hair pattern.

The invention accordingly provides, in another aspect, an apparatus for locating the center of a cross-hair, made up of intersecting lines, contained in an input image. That apparatus is constructed and operated as described above, and is additionally adapted to take projections along two axes, each of which is aligned with an expected orientation of the corresponding hairs. That apparatus also performs mirror symmetry and notch-detection filtering on both projections to permit location of the centers of each hair. The center of the cross-hair is, then, determined to lie at the intersection of the hairs.

In still other aspects, the invention provides methods for linear pattern location corresponding to the operation of the apparatus described above.

As will be appreciated from this summary, and from the subsequent detailed description, features of the invention include its ability to locate linear patterns without matching them with image templates, as otherwise required in the prior art. Another feature of the invention is its ability to detect very low contrast linear patterns and pattern edges. This results, in part, from the use of projections which greatly enhance the signal-to-noise ratio of the image signal. Moreover, the invention demands two-dimensional processing only for the generation of projections, utilizing single-dimensional processing for all other sophisticated operations.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features, objects and benefits of the invention can be more clearly understood with reference to the following description of an illustrative embodiment, and to the drawings, in which:

FIG. 1 is a schematic representation of a preferred embodiment of an apparatus according to the invention;

FIG. 2 is a perspective view of a linear pattern on a surface;

FIG. 3 is a planar view of a representative segment of an image signal and corresponding projections;

FIG. 4*a* is a plot of a projection signal;

FIG. 4*b* is a detail of the plot of a projection signal taken along lines A—A;

FIG. 4*c* is a plot of a mirror symmetry signal;

FIG. 4*d* is a plot of an output of a notch-detection element; and

FIG. 5 is a diagram showing the function of the peak locating element.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

With reference now to FIGS. **1** and **2**, a schematic representation of an apparatus **10** for accurately locating a cross-hair **12**, comprising intersecting linear patterns **12***a*, **12***b* is shown on a surface **14**.

The surface **14** is illuminated, for example, by lamps **16** to facilitate the creation of an image signal by a video camera **18**. The output of that camera is electrically connected to an optional storage device **20** that can store the image prior to processing. As shown in the illustration, the output of storage device **20** is routed to a projection element **30**, which performs the first stage of location processing, as discussed below.

Video camera **18**, lamps **16**, and storage device **20** operate and are configured in a manner conventional in the art.

A digital image signal **22** output by camera **18** is made up of individual pixels, $I_{x,y}$. A representative portion **23** of an image signal **22** is illustrated in FIG. **3**, showing pixels designated $I_{1,1}$, $I_{1,2}$, . . . $I_{4,5}$.

The projection element **30** sums pixels along directions parallel to axes **36***a*, **36***b* corresponding to the expected orientation of the linear patterns **12***a*, **12***b* to be inspected. For example, if the linear patterns are oriented with the pixel grid itself, the projection summations are conducted along the grid's rows and columns; otherwise, they are conducted in appropriate directions. The projection element generates, for those sums, projection signals **32***a*, **32***b*, respectively.

The aforementioned projection signals can be generated in a manner conventional in the art. Preferably, they are generated in accord with the techniques revealed in U.S. Pat. No. 4,972,359, assigned to the assignee hereof. A software listing of a more preferred implementation of projection element **30** is provided in Appendix A, filed herewith.

By way of example, illustrated projection signal **32***a* includes elements Pa_1 through Pa_4, generated in accord with the following mathematical function (which assumes that the pixel grid is aligned with the axes **36***a*, **36***b*).

$$Pa_i = \sum_{n=1}^{5} I_{i,n} \qquad \text{Eq. 1}$$

Projection signal **32***b*, including elements Pb1 through Pb5, is generated by a like formula.

As noted above, each projection signal **32** provides a profile of the image signal **22** in a direction parallel to the corresponding axis. Thus, the linear pattern aligned with the axis is emphasized, while image "noise" is effectively averaged out.

For sake of simplicity, the discussion which follows focuses on processing of a projection signal corresponding to a single linear pattern, e.g., "hair" **12***a* of cross-hair **12**. It will be appreciated that, in order to determine the location of cross-hair **12**, like processing is performed on the other "hair" **12***b*.

An exemplary projection signal **32** is illustrated in FIG. **4***a*, where three features of interest are shown: the portions **36**, corresponding to the average background intensity value of the image scene; the portion **39** corresponding to the average intensity value of the central region of the linear pattern or "hair"; and the portion **38**, corresponding to the average intensity of the boundary between the linear feature and the background. It will be appreciated that the features **38** and **39** can be relatively brighter than, darker than, or equal to, the background **36**, in any combination. It will be further appreciated, however, that features **38** and **39** cannot both be equal to the background, because the pattern would not be detectable. Further fluctuation in the illustrated projection signal **32** is due, for example, to noise in the image signal **22**.

The image processor **10** performs further processing on the projection signal in order to provide an accurate indication of the location of the center of the linear pattern **12***a* on the surface **14**. Particularly, referring to FIG. **1**, exemplary projection signal **32** is processed by mirror symmetry filter element **50**, using an input radius r, to derive a peak corresponding to the center of the pattern **12***a*. The radius, r, represents one-half of the expected width of the linear pattern, and is illustrated as **42** of FIG. **4***b*.

The radius r is input, for example, by the user, e.g., via console **90**. The value of radius r is selected to accommodate the expected variation of thickness in the linear pattern caused by, for example, processing of the underlying component. While the exact value of the radius, r, is not critical, it is preferably selected to be slightly larger than the largest expected half-width of the linear pattern.

Mirror symmetry filter element generates the filtered signal, S, from exemplary projection signal P and corresponding radius, r, in accord with the mathematical function

$$Si = \sum_{a=1}^{r} |P_{i+a} - P_{i-a}| \qquad \text{Eq. 2a}$$

for each value of i between r and the length of the projection signal P minus r.

Alternatively, the mirror symmetry filter element can generate the filtered signal, S, in accord with the mathematical function

$$Si = \sum_{a=0}^{r-1} |P_{i+a} - P_{i-a-1}| \qquad \text{Eq. 2b}$$

Those skilled in the art will appreciate that Equations 2a and 2b, while similar, produce resultant signals S which are effectively one-half pixel out of phase with one another.

With respect to Eqs. 2a and 2b, at each point i along an axis **36**, the projection signal **32** value between zero and r on the left side of the point is subtracted from the value the same distance to the right of the point. An absolute value is calculated, and is added to the absolute values of the differences at the other points between zero and r. This gives an indication of how mirror symmetric the projection **32** is about point i. The same algorithm is run along the length of the projection signal **32**, giving an indication of the overall symmetrical quality of the projection signal **32**.

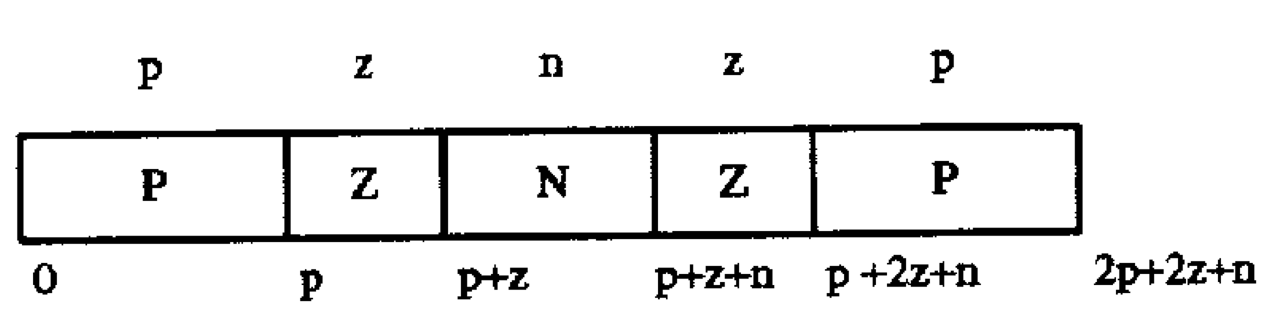
As illustrated in FIG. **4c**, the mirror symmetry signal **52** is low, indicating a high degree of symmetry, in regions of approximately uniform background, e.g., at distances more than one radius away from the linear pattern **12a**. Within one radius of the pattern, the value of S rises, indicating a low degree of symmetry. The signal S remains relatively high at all points within radius r of the center of the pattern, except for a very small region surrounding the exact center of the feature. This is revealed as a very sharp, downward spike **56** in signal S, whose extreme point **54** corresponds to the center of the exemplary linear pattern **12a**.

The apparatus **10** performs still further processing in order to identify the location of the center of the linear pattern **12a**. The goal is to distinguish the low signal value **56**, corresponding to the true center of the linear pattern **12a**, from the other low values corresponding to the uniform background. This is performed by notch detection element **60**, which operates on the mirror symmetry signal S with a mask to generate a peak location signal L further emphasizing the peak **56**.

The notch detector element **60** generates the peak location signal L in accord with the mathematical function:

$$L_i = \min\left(\frac{1}{p}\sum_{j=0}^{p-1} S_{i+j},\ \frac{1}{p}\sum_{j=p+2z+n}^{2p+2z+n-1} S_{i+j}\right) - \frac{1}{n}\sum_{j=p+z}^{p+z+n-1} S_{i+j} \qquad \text{Eq. 3}$$

based on a mask, M, which can be depicted as follows:



In a preferred embodiment, the notch mask has a central notch one pixel wide of negative one unit amplitude. On either side of the notch, there are one pixel wide shoulders of zero amplitude. At the far ends, the shoulders notches are two pixels wide and positive one-half unit high. That is, p=2, z=1 and n=1, while P=½, Z=0 and N=−1. This preferred mask is as follows:

½ ½ 0 −1 0 ½ ½

In effect, a mask of this shape represents a negative-going notch locator, filtering out all areas of the symmetry signal **52** which are low due to the uniform background. The result of the operation of this filter on the mirror symmetry signal **52** of FIG. **4c** is illustrated in FIG. **4d**.

The spike **62** and its peak **64** represent an accurate indication of the relative position of the center **11a** of the exemplary linear pattern **12a** parallel the axis **36** of interest.

In a less preferred embodiment, the function of notch detection element **60** may be performed by a laplacian filter element, which convolves the mirror symmetry signal S with a mask to generate a peak location signal L further emphasizing the peak **56**.

As those skilled in the art will appreciate, convolution involves taking the "dot product" of successive overlapping windows of the mirror symmetry signal S with a pixel mask M, having elements $M_1, M_2, \ldots M_k$. Thus, the laplacian estimator element **60** generates the peak location signal L in accord with the mathematical function:

$$Li = \sum_{j=1}^{k} S(i+j-1) \cdot M_j \qquad \text{Eq. 4}$$

A mask for such an operation is as follows:

¼ −¼ 0 1 0 −¼ −¼

A further refinement of the position of the peak **56** is made possible by implementing a peak location element **70** as illustrated in FIG. **1**.

Referring to FIG. **5**, the point which has the highest amplitude in spike **62**—i.e., the point representing the apparent peak of the peak location signal L—is identified as point **72**. On either side of that point **72** are neighboring points **74** and **76**.

In order to better determine the actual peak, and thereby the actual center of the linear pattern **12a**, the peak location element **70** determines the location of a point **84** representing the intersection of lines **78** and **80**. The line **78** is determined as that line which connects apparent peak **72** and lowest-value neighbor **76**, while line **80** is determined as that line passing through highest-value neighbor **74** and having a slope **82** which is the negative of that of line **78**, as illustrated.

The point **84** where the two line segments **78**, **80** intersect is identified as a truer approximation of the center **11a** of the linear pattern **12a**.

In an alternative to the aforementioned method of peak detection, the processor **10** generates two mirror symmetry signals, S_1 and S_2, from each projection signal, P. The first mirror symmetry signal S_1 is generated according to Eq. 2a, while the second, S_2, is generated according to Eq. 2b. Each of the signals S_1, S_2 are then passed through notch detection element **60** to produce notch detection signals L_1 and L_2, respectively. Peak detection proceeds as described above, except insofar as apparent peak point **72** is determined by signal L_1, while neighboring points **74** and **76** are determined by signal L_2.

In order to determine the coordinates **11** of a cross-hair pattern **12**, the apparatus **10** generates a projection signal Pa, Pb of the image signal I along respective axes **36a**, **36b**. It then uses the input radius r associated with each of those projections. The apparatus, in turn, determines a mirror symmetry signal Sa, Sb corresponding to respective ones of the projections signals Pa, Pb. And, from those mirror symmetry signals Sa, Sb, the apparatus generates peak location signals La, Lb, respectively.

Upon locating the center of the corresponding linear patterns **12a**, **12b** in the manner described above, the apparatus **10** generates a signal representing the center of the cross-hair **12** at the point of intersection of the two patterns **12a**, **12b**. That signal may be then be output to terminal **90** or positioning apparatus, not shown.

A further understanding of the invention may be attained by reference to Appendix A, filed herewith, disclosing a preferred software implementation of aspects of the invention described and claimed herein.

SUMMARY

Described above are improved machine vision methods and apparatus capable of quickly and accurately locating linear patterns, such as wafer streets or cross-hairs, on a component. Unlike the prior art, systems constructed in accord with the invention does not require an input template pattern.

Those skilled in the art will appreciate that the embodiments described above are illustrative only, and that other systems in the spirit of the teachings herein fall within the scope of the invention. Thus, for example, it will be appreciated that methods and apparatus other than that described above for mirror symmetry filtering can be used. Likewise, the invention embraces methods other than notch detection (e.g., the Laplacian technique disclosed above) for filtering the output of the mirror symmetry filter. Still further, the use of peak detection methodologies and apparatus other than, but falling within the spirit of, those described above is contemplated by the invention. Moreover, it will be appreciated that the methods and apparatus described herein can be used to identify linear patterns other than "streets" and cross-hairs.

And, of course, that systems constructed in accord with the invention have applicability outside the field of semiconductor wafer processing. Thus, for example, they can be used to locate cross-hairs in connection with graphics printing of color overlays, and in positioning components during parts assembly or inspection.

These and other such uses, as well as modifications, additions and deletions to the techniques described herein may fall within the scope of the invention.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appendix
~~Attachment~~ A

to

Patent Application for
METHOD AND APPARATUS FOR LOCATING
PATTERNS IN AN OPTICAL IMAGE

C Language
Software Listing of Preferred Implementation

92/01/28
11:38:15

cross_finder.v

1

```
/*
 *
 *      Copyright (c) $Date$
 *      Cognex Corporation, Needham, MA 02194
 *
 *      $Source$ yor:/home/milind/mrs/patent/cross_finder.v
 *      $Revision$
 *      $Locker$
 *
 */

static  char    *header = "$Header$";

/*
  Defines the three functions that are used for:
  1. Projection.
  2. Applying a symmetry filter to the image.
  3. Applying a Laplace filter to the image.
  */

/****************************************
 ** f_project *** Image Projection      *
 ****************************************
 **
 */
cip_buffer *f_p(buff,proj_buff,angle)
cip_buffer *buff, *proj_buff;
double angle;
{
  short i;
  ctm_timer time_1;
  cmap_params *mp_param;

  mp_param=(cmap_params *)cvc_alloc(sizeof(cmap_params));
  cu_clear(mp_param,sizeof(cmap_params));

  mp_param->wf = cmap_identity;
  mp_param->mp.ab.zero = 0;
  mp_param->mp.ab.one = (int)pow(2.0,(double)buff->depth) - 1;

  ctm_begin(&time_1);
  proj_buff = cpro_project(buff,0,mp_param,angle);
/*
  printf("\nProjection time %d",ctm_read(&time_1));
*/

  free(mp_param);
  mp_param = NULL;

  return proj_buff;
}
```

```
/*****************************************
 ** f_s **** Symmetry Filter            *
 *****************************************
 **
 */
cip_buffer *f_s(buff,sym_buff,sym_filter_size)
cip_buffer *buff, *sym_buff;
int sym_filter_size;
{
  int i,j,sym_val,buff_end;
  ctm_timer time_1;

  if(!sym_buff) {
    sym_buff = cip_create(buff->width,1,32);
  }
  cip_set(sym_buff,0);

  buff_end = buff->width - sym_filter_size;
  sym_val = 0;

  ctm_begin(&time_1);
  for(i=sym_filter_size;i<buff_end;i++) {
    for(j=0;j<sym_filter_size;j++) {
      sym_val += abs(buff->get(buff,i-j,0) - buff->get(buff,i+j,0));
    }
    sym_buff->put(sym_buff,i,0,sym_val);
    sym_val = 0;
  }
/*
  printf(" ,Symmetry Filter time = %d",ctm_read(&time_1));
*/

  return sym_buff;
}
```

92/01/28
11:38:15

cross_finder.v

3

```
/*****************************************
** f_1 **** Laplace Filter              *
*****************************************
**
.            (+)
.             --
.            |  |
.        0   |  |
.---------------------------------
.|    |           |    |
.|    |           |____|
. ----             ----
. (-)              (-)

30,0,2
*/
cip_buffer *f_1(buff,lap_buff,sym_filter_size,lap_zero,lap_one)
cip_buffer *buff, *lap_buff;
int sym_filter_size, lap_zero, lap_one;
{
  int i,j,buff_start,buff_end,lap_val,lap_end;
  int lap_left, lap_right;
  ctm_timer time_1;

  if(!lap_buff) {
    lap_buff = cip_create(buff->width,1,32);
  }

  cip_set(lap_buff,0);

  buff_start = sym_filter_size+lap_zero+lap_one;
  buff_end = buff->width-sym_filter_size-lap_zero-lap_one;

  lap_end = lap_zero+lap_one;
  lap_left = 0;
  lap_right = 0;

  ctm_begin(&time_1);
  for(i=buff_start;i<buff_end;i++) {
    lap_val=lap_end*buff->get(buff,i,0);
    for(j=lap_zero+1;j<=lap_end;j++) {
      lap_val -= MIN(buff->get(buff,i-j,0),buff->get(buff,i+j,0));
    }
    lap_buff->put(lap_buff,i,0,lap_val);
  }
 /*
  printf(" ,Laplace Filter time = %d\n",ctm_read(&time_1));
 */

  return lap_buff;
}
```

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cross_finder.v

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```
/*****************************************
 ** f_m **** Finding Max value          *
 *****************************************
 **
 */
int f_m(buff,flag,sym_filter_size,lap)
cip_buffer *buff;
bool flag;
int sym_filter_size,lap;
{
  int i;
  int max_pix,max_i;
  int buff_start, buff_end;

  max_pix=0;
  max_i = 0;

  buff_start = sym_filter_size+lap;
  buff_end = buff->width-sym_filter_size-lap;

  for(i=buff_start;i<buff_end;i++) {
    max_pix = MAX(max_pix,buff->get(buff,i,0));
    if(max_pix == buff->get(buff,i,0)) {
      max_i = i;
    }
  }

  if(flag)   return max_i;
  else       return max_pix;

}
```

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```
/*****************************************
 ** f_min_pix_pos **** Finding Min value*
 *****************************************
 **
 */
int f_min_pix_pos(buff,flag,sym_filter_size,lap)
cip_buffer *buff;
bool flag;
int sym_filter_size,lap;
{
  int i;
  int min_pix,min_i;
  int buff_start, buff_end;

  min_pix=buff->get(buff,(int)buff->width/2,0);
  min_i = 0;

  buff_start = sym_filter_size+lap;
  buff_end = buff->width-sym_filter_size-lap;

  /* exclude zeros */
  for(i=buff_start;i<buff_end;i++) {
    if(buff->get(buff,i,0)) {
      min_pix = MIN(min_pix,buff->get(buff,i,0));
      if(min_pix == buff->get(buff,i,0)) {
        min_i = i;
      }
    }
  }

  if(flag)    return min_i;
  else        return min_pix;

}
```

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```
/*****************************************
** iclp_plot1d_in_window **** Plot     *
*****************************************
**
*/
double
  iclp_plot1d_in_window (data, window_, horiz_, signed_, connect_,
                         xscale_, xoffset_, max_pel_,
                         fgnd_, bgnd_, border1_, border2_)
cip_buffer      *data, *window_;
bool            horiz_, signed_, connect_;
double          xscale_, xoffset_;
int             max_pel_;
int             fgnd_, bgnd_, border1_, border2_;
{
  cip_buffer    window, plot;
  bool          horiz, signed, connect;
  double        xscale, xoffset;
  int           max_pel;
  double        yscale, yoffset;
  double        ymin, ymax;
  int           fgnd, bgnd, border1, border2;
  int           depth, size;

  depth = data->depth;

  if (window_) {
    cu_copy (window_, &window, sizeof(cip_buffer));
    horiz = horiz_; signed = signed_; connect = connect_;
    xscale = xscale_; xoffset = xoffset_;
    max_pel = max_pel_;
    fgnd = fgnd_; bgnd = bgnd_, border1 = border1_; border2 = border2_;
  }
  else {
    horiz = 1; signed = (depth > 8); connect = 1;
    xscale = 1.; xoffset = 0.;
    max_pel = 0;
    fgnd = 63; bgnd = 32; border1 = 0; border2 = 32;
    cip_window (caq_image, &window,
                (caq_image->width - data->width - 2)/2,
                (caq_image->height - 130)/2,
                data->width + 2, 130);
  }

  cgr_outline (&window, border1);
  cip_window (&window, &plot, 1, 1, window.width - 2, window.height - 2);
  size = ((horiz) ? plot.height : plot.width);
  if (bgnd >= 0) cip_set (&plot, bgnd);

  {
    int         i, p;
    double      y;

    for (i = 0; i < data->width; i++) {
      p = data->get (data, i, 0);
      if (signed) switch (depth) {
        case 8:  y = (int) ((char) (p & 0xff)); break;
        case 16: y = (int) ((short) (p & 0xffff)); break;
        default: y = p; break;
      }
      else switch (depth) {
        case 8:  y = (unsigned int) ((unsigned char) (p & 0xff)); break;
        case 16: y = (unsigned int) ((unsigned short) (p & 0xffff)); break;
```

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```
      default: y = (unsigned int) p; break;
    }
    if (i == 0) ymax = ymin = y;
    else if (y < ymin) ymin = y;
    else if (y > ymax) ymax = y;
  }
  if (max_pel && ymax <= max_pel && ymin >= ((signed) ? - max_pel : 0)) {
    ymax = max_pel;
    ymin = (signed) ? -max_pel : 0;
  }
  if (!window_ && signed && ymin >= 0) signed = 0;
  if (signed) {
    ymax = (ymax > -ymin) ? ymax : -ymin;
    ymin = -ymax;
  }
  else ymin = 0.;
  if (ymax - ymin != 0.)
    yscale = -(size - 1) / (ymax - ymin);
  else
    yscale = -(size - 1) / 64;
  yoffset = ymax * -yscale;
}

{
  int         i, j, ink, y;
  double      step;

  for (i = 3; i >= 0; i--) {
    step = ymax / (1 << i);
    ink = (border1 + ((1 << i) - 1) * border2) / (1 << i);
    for (j = 2 << i; j; j--) {
      y = yoffset + yscale * (ymax - j * step);
      if (horiz)
        cgr_iline (&plot, 0, y, plot.width-1, y, ink);
      else
        cgr_iline (&plot, y, 0, y, plot.height-1, ink);
    }
  }
}

{
  int i, x, y, p, old_x = -1, old_y = -1;

  for (i = 0; i < data->width; i++) {
    x = i * xscale + xoffset + 0.5;
    p = data->get (data, i, 0);
    if (signed) switch (depth) {
      case 8:  y = yoffset + yscale * ( (int) ((char) (p & 0xff)) ); break;
      case 16: y = yoffset + yscale * (short) p; break;
      case 32: y = yoffset + yscale * (long)  p; break;
      default: y = yoffset + yscale * (long)  p; break;
    }
    else switch (depth) {
      case 8:  y = yoffset + yscale * ( (int) ((unsigned char) (p & 0xff)) ); break;
      case 16: y = yoffset + yscale * (unsigned short) p; break;
      case 32: y = yoffset + yscale * (unsigned long)  p; break;
      default: y = yoffset + yscale * (unsigned long)  p; break;
    }
    if (horiz) {
      if (x >= 0 && x < plot.width && y >= 0 && y < plot.height) {
        if (connect && old_x >= 0)
          cgr_line (&plot, old_x, old_y, x, y, fgnd);
        else
          plot.put (&plot, x, y, fgnd);
```

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```
            old_x = x;
            old_y = y;
          }
          else old_x = -1;
        }
        else {
          if (y >= 0 && y < plot.width && x >= 0 && x < plot.height) {
            if (connect && old_y >= 0)
              cgr_line (&plot, old_y, old_x, y, x, fgnd);
            else
              plot.put (&plot, y, x, fgnd);
            old_x = x;
            old_y = y;
          }
          else old_y = -1;
        }
      }
    }

    return yscale;
  }
/****************************************/
```

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```
/*
 *      Copyright (c) $Date: 91/11/21 16:34:25 $
 *      Cognex Corporation, Needham, MA 02194
 *
 *      $Source: /nfs/lex/products/x000/src/cpro/image_project.c,v $
 *      $Revision: 1.13 $
 *      $Author: scl $
 *      $Locker:  $
 */

/* ++ */
/* image_project()
 * Project Image onto Line at Arbitrary Angle
 * For now, works only between -45 and +45 degrees.
 */
/* -- */

static char    *header = "$Header: /nfs/lex/products/x000/src/cpro/image_project.c,v 1.13
 91/11/21 16:34:25 scl Exp $";

#include <which_bd.h>
#if C_BOARD==C_UNIX
#include <histogram_def.h>
histogram *image_project()
{ unsupported ("image_project");
}
#endif

#if C_BOARD!=C_UNIX
#include <cip.h>
#include <cct.h>
#include <cpro_er.h>
#include <cpro_def.h>
#include <cchk_er.h>
#include <blob.h>
#include <vm7s_def.h>
#include <vcp.h>

extern void project_strip();
extern int project_table [16];

static char loop_adjust_table [16] =
  { 0, 0, 0, 0,
    1, 0, 0, 0,
    1, 1, 0, 0,
    1, 0, 0, 0};


/* loop_control() returns values in d5,d6,d7 which are used to
 * control the execution of project_strip(). If project_strip() is to
 * be called in a loop, using the same control values, the variable
 * "width" passed to loop_control() must be even to preserve the image
 * and model alignment.
 */

void loop_control (image, width, d5, d6, d7)
  register cip_buffer *image;
  register int width;
  int *d5, *d6, *d7;
  { register int
      code,
      wodd,
      weven;
```

```
    code = (((int)(image->rat[0] + image->x_offset) & 1) << 3) + (width & 3);
    weven = (width >> 2) - loop_adjust_table [code];
    wodd  = (width >> 2) - loop_adjust_table [code + 4];

    /* There is a special case when the image alignment is odd, the
     * model alignment is even, and the width is 1.
     */

    if (weven < 0)
      { weven = 0;
        *d5 = ((project_table[code + 4] - project_table [0])
              & 0xFFFF) * 0x10001;
      }
    else
      *d5 = ((project_table [code] - project_table [0]) & 0xFFFF) +
            ((project_table [code + 4] - project_table [0]) << 16);

    *d6 = ((8 - (weven & 7)) + ((8 - (wodd & 7)) << 16)) << 1;

    *d7 = (weven >> 3) + ((wodd >> 3) << 16);
  }


histogram *image_project (ip, tan_theta, projection, z_hist)
register cip_buffer *ip;
int tan_theta;
histogram *projection;
histogram **z_hist;
  {
    int bn, *bins;          /* # and address of bins needed for projection  */
    int ix, sw;             /* Image strip offset + I_load, strip width     */
    int d5, d6, d7;         /* Loop control registers                       */
    int n;                  /* Number of pixels per strip.                  */

    histogram *ehp;                         /* -> E histogram               */
    histogram *(*zhist_function)();
    register histogram *ph;                 /* projection histogram */
    register int i, *bp;                    /* counter, bin pointer */

    struct                  /* This histogram is for reading the E array in */
      { histogram h;        /* case the caller doesn't want it so we can do */
        int bins[256];      /* a consistency check                          */
      }
      eh;

    /* If no projection was supplied, make one                              */

    bn = CPRO_BINS( ip-> width, ip-> height, tan_theta );

    if (!(ph = projection)) ph = make_hist (bn);
    else if (ph->bins < bn) cct_error (CPRO_ERR_BINS);

    /* Set range and clear the bins                                         */

    bins = (int *)(ph + 1);
    for (i = ph->range = bn, bp = bins; i; --i) *bp++ = 0;

    /* Return z histogram in z_hist if requested.
     * Otherwise use the internal histogram "eh".
     */

    eh.h.bins = 256;
```

```
eh.h.valid = 0;
ehp = z_hist ? *z_hist : &eh.h;

/* Loop over all of the strips. Pick an even strip width such that the
 * number of enclosed pixels is less than 65K.
 */

sw = ip->width == 1 ? 1 :
  min(min( 0x10000/ip->height, 254 ), ip->width ) & 0xfffe;

n = ip-> height * sw;
loop_control (ip, sw, &d5, &d6, &d7);

/* The z histogram is initialized with write_zhist(), and accumulated
 * using add_zhist(). This is necessary to avoid E array bin overflow.
 */

zhist_function = write_zhist;

grab_vm7s();

if( tan_theta >= 0 )
  {
    bp = bins;

    for( i=ip->width, ix=ip->x_offset + I_load; i>0; i -= sw, ix += sw )
      {
        if( i < sw ) /* Last time through */
          {
            sw = i;
            n = ip->height * sw;
            loop_control( ip, sw, &d5, &d6, &d7 );
          }

        project_strip(ip->rat,ix, bp, tan_theta, sw, ip->height, d5,d6,d7);
        zhist_function( ehp, n );
        zhist_function = add_zhist;

        bp += sw;
      }
  }
else /* tan_theta < 0 */
  {
    bp = bins + max( ip->width - sw, 0 );

    for( i=ip->width, ix=ip->x_offset + I_load; i>0; i -= sw, ix += sw )
      {
        if( i < sw ) /* Last time through */
          {
            sw = i;
            n = ip->height * sw;
            loop_control( ip, sw, &d5, &d6, &d7 );
          }

        project_strip(ip->rat,ix, bp, tan_theta, sw, ip->height, d5,d6,d7);
        zhist_function( ehp, n );
        zhist_function = add_zhist;

        bp += -min( i - sw, sw );
      }
  }

vm7s_inuse = 0;
```

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```
    /* Clear ehp-> m1_valid that (write,add)_zhist() set because mom1
     * was read from C[0], but when using project_strip() it isn't valid.
     * Finally, check that the E first moment equals the projection
     * 0th moment.
     */

    ph->n = ip->width * ip->height;
    ph->valid = (1<<bn_valid) | (1<<n_valid);
    moments (ph);

    ehp->valid &= ~(1 << m1_valid);
    moments (ehp);

    if (ehp->mom1l != ph->mom0 || ehp->mom1h)
      { if (!projection) free (ph);
        cct_error (CCHK_ERR_CHK);
      }

     return ph;
  }
#endif
```

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```
/*
 * Copyright (c)
 * $Date: 91/11/21 16:20:51 $
 * Cognex Corporation
 * Needham, Massachusetts
 *
 * $Source: /nfs/lex/products/x000/defs/histogram_def.h,v $
 * $Revision: 1.7 $
 * $Author: scl $
 *
 */
#ifndef _histogram_def_
#define _histogram_def_

/*      ************************************
        *                                  *
        *  A Histogram and Associated Data *
        *                                  *
        ************************************

A histogram consists of a header structure and some number of longword
data bins, allocated as one contiguous region of memory. The header holds
some bookkeeping information and has slots for every quantity that I thought
you might want to derive from a histogram. The bins define a one-dimensional
function h(i), where i is the bin index and h(i) is the contents of bin i.
The bins are always numbered starting with 0.

In typical use, make_hist is called to allocate an empty histogram. The
vm7/s translation table is set up and a vm7/s routine is called to fill
in the bins from an image. Histogram processing routines are then called
to fill in the derived quantities as needed. Finally, the histogram is
deallocated with a call to free. Other variations are possible, of course.
If the number of bins is known at compile time, a histogram can be allocated
as an automatic variable on the stack (a struct consisting of a header
followed by the bins, for example). The histogram need not be computed by
vm7/s or even from an image.

For each quantity in the histogram, including the bins and all derived
quantities, there is a bit in the header element "valid" that if set
indicates that the corresponding quantity has been computed and should be
considered valid. The function make_hist clears all valid bits. The
routine that fills in the bins will set bn_valid and n_valid, and possibly
some of the moments if known. The rest of the bits are set as the quantities
are computed.

The valid bits have three purposes: 1) To prevent inadvertant
use of the bins before they are filled in. 2) To save time by allowing
routines to compute just the quantities that they need without computing
```

```
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any quantity more than once. 3) To provide hardware and software
redundency checks. Any routine that as part of its normal operation can
compute a quantity at no significant cost, should do so regardless of
whether that quantity has been asked for or is already valid. If the
quantity is already valid the recomputed value is checked against the
value already in the header, and a throw or chk trap is taken if they
disagree. Redundency checking is very important for vm7/s operation,
where subtle hardware and software problems might exist and a significant
amount of redundent information is available. For example, one serious
software problem that can be detected is failing to observe the convention
that the entire E and C arrays must be left 0 by any routine using vm7/s.

One of the derived quantities in the header is the 101 element array "ic",
which is the inverse of the cumulative function of h(i). The index of ic
is measured in percent, from 0 to 100 inclusive. The quantity ic[j] is a
histogram bin index, such that j percent of the area under the function
h(i) is at or to the left of that bin. More precisely, ic[j] is the
smallest integer such that

               ic[j]
               -----
      1          \                  j
    ------        >   h (i)  >=   -----
     mom0        /                 100
               -----
               i = 0

except for j = 0, where the ">=" is replaced with a ">".
The inverse cumulative has many uses. ic[50] is the median (blue dot)
of h(i). Left and right tails can be looked up directly from parameters
expressed in percent, for example ic[5] and ic[95] for 5% tails. Min and
max image values can also be looked up -- they are ic[0] and ic[100].
All of these quantities are important both for grey scale histograms
and spatial histograms.
*/

/* The histogram header.                                                */
typedef struct
  { short
      bins,              /* number of histogram bins available          */
      range;             /* number of bins in use                       */
    unsigned int
      valid,             /* "Valid" bits for derived quantities.        */
      n,                 /* Number of samples used to make the histogram */
      mom0,              /* 0th moment: SUM [h(i)]                      */
      mom1h,             /* 1st moment: SUM [i*h(i)] High order part.   */
      mom1l,             /* Low part of 1st moment                      */
      mom2h,             /* 2nd moment: SUM [i*i*h(i)] High order part. */
      mom2l,             /* Low order part of 2nd moment.               */
      mean_sample,       /* (mom0 / n) * 100                            */
```

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```
      mean_x,            /* (mom1 / mom0) * 100                        */
      variance,          /* (mom2 - mom1 * mom1 / n) / n * 100         */
      sd;                /* sqrt (variance) * 100                      */
    short
      ic [101];          /* inverse of cumulative.                     */
  }
  histogram;

/* Histogram valid bit assignments. This is done as an enumeration
   type so that the values can be made available to assembler code
   with h2m68.
*/
enum valid_bits
  { bn_valid,  n_valid, m0_valid, m1_valid,
    m2_valid, ms_valid, mx_valid, vr_valid,
    sd_valid, ic_valid
  };


/* This structure contains the histogram structure & bins for
 * an intensity histogram.
 */

#define Z_BINS 256

typedef struct z_histogram
  { histogram h;          /* The histogram header */
    int bins[ Z_BINS ]; /* The histogram bins   */
  }
z_histogram;

#endif
```

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```
*       Copyright (c) $Date: 90/08/16 15:59:53 $ Cognex Corporation, Needham, MA 02194
*
*       $Source: /nfs/lex/products/x000/src/cpro/vp_project_strip.m68,v $
*       $Revision: 1.8 $
*       $Author: peter $
*       $Locker:  $

        ;*******************************************************
        ;                                                     *
        ;  Project Strip of Image onto Line at Arbitrary Angle *
        ;                                                     *
        ;*******************************************************

* For now, the same code runs on VM8 and VM10.  The optimal code on
* VM10 should use the A-register mode.

        nolist
        include section.168
        include which_bd.168
        ifne    C_BOARD-C_UNIX
        include argoff.168
        include vcp.168
        include rept.168
        list

        our_section data

        DC      '$Source: /nfs/lex/products/x000/src/cpro/vp_project_strip.m68,v $'
        DC      '$Revision: 1.8 $'

        xdef    _project_strip,_project_table

* void project_strip (rat, ioffset, bins, tan_theta, width, height, d5, d6, d7)
*   char **rat;          /* RAT from image                              */
*   int
*     ioffset,           /* offset of strip, + I_load                   */
*     *bins,             /* starting address for bins of projection     */
*     tan_theta,         /* tan(theta) (31.16)                          */
*     width,             /* width of strip, <= 254                      */
*     height,            /* height of strip                             */
*     d5, d6, d7;        /* initializers for loop control registers     */

* register save list
rsl     reg     d0-d7/a0-a6

        ;****************
        ;               *
        ;  Entry Point  *
        ;               *
```

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```
        ;****************

* registers:
*       d0
*       d1       model address increment (32.16)
*       d2       row counter
*       d3       model address offset, fractional part (32.16)
*       d4       inner loop counter
*       d5       row entry point offset pair
*       d6       inner loop entry point offset pair
*       d7       inner loop count pair
*       a0       -> model codes during loop
*       a1       -> image pixels during loop
*       a2       -> image RAT
*       a3       -> next C element to read
*       a4       -> next histogram bin to write
*       a5       -> model codes for start of row

        our_section     fast
_project_strip:
        link    a6,#0
        movem.l rsl,-(sp)

* initialization
        movem.l arg6$l(a6),d2/d5-d7     * load a bunch of registers from args
        subq.w  #1,d2                   * for dbf
        moveq   #0,d3                   * 0 model offset
        move.l  arg1$l(a6),a2           * -> RAT
        move.l  #C_array,a3             * -> C array
        move.l  arg3$l(a6),a4           * -> next bin
        move.l  #model_codes,a5         * a5 -> model codes
        move.l  arg4$l(a6),d1           * tan(theta) -> d1
        bpl.s   .20                     * <0?
        neg.l   d1                      * yes, abs(tan(theta))
        lea     254(a5),a5              * adjust model code pointer
        move.w  arg5$w(a6),d0           * adjust C array pointer
        lsl.w   #2,d0
        add.w   d0,a3
.20     bra.s   .10

nextrow:
        add.l   d1,d3                   * update model offset
        bclr    #16,d3                  * overflow to integer part?
        beq.s   .10
        swap    d6                      * yes, swap odd/even model alignment
        swap    d5
        swap    d7

        tst.w   arg4$l(a6)              * tan(theta) >= 0?
        bmi.s   .11
```

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```
        move.l  (a3)+,d0            * yes, update next projection bin
        add.l   d0,(a4)+
        addq.l  #1,a5               * advance model pointer
        tst.b   (a5)                * handle wrap around
        bne.s   .10
        lea     -254*4(a3),a3       * wrap C pointer
        lea     -254(a5),a5         * wrap M pointer
        bra.s   .10

.11:    move.l  -(a3),d0            * tan(theta) < 0, update projection
        add.l   d0,(a4)+            * bin
        tst.b   -(a5)               * advance model pointer
        bne.s   .12                 * wrap model pointer?
        lea     254(a5),a5          * yes
.12:    cmp.l   #C_array,a3         * wrap C pointer?
        bne.s   .10
        lea     254*4(a3),a3        * yes

.10:    move.w  d7,d4               * init inner loop counter
        move.l  a5,a0               * starting address for model codes
        add.l   #M_load,a0
        move.l  (a2)+,a1            * starting address for next image row
        add.l   arg2$1(a6),a1
        jmp     ee0(pc,d5.w)        * jump to 1 of 16 possible entry
                                    ; points depending on alignment
                                    ; and width % 4

oo3:    cmpm.b  (a0)+,(a1)+
ee2:    cmpm.w  (a0)+,(a1)+
ee0:    jmp     loop0(pc,d6.w)

oo0:    cmpm.b  (a0)+,(a1)+
ee3:    cmpm.w  (a0)+,(a1)+
ee1:    jmp     loop1(pc,d6.w)

oo1:    cmpm.b  (a0)+,(a1)+
        jmp     loop0(pc,d6.w)

oo2:    cmpm.b  (a0)+,(a1)+
        jmp     loop1(pc,d6.w)

oe0:    tst.w   (a0)+
        tst.b   (a1)+
        cmpm.w  (a0)+,(a1)+
        jmp     loop2(pc,d6.w)

oe1:    tst.w   (a0)+
        tst.b   (a1)+
        cmpm.w  (a0)+,(a1)+
        jmp     loop3(pc,d6.w)
```

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```
oe2:    tst.w   (a0)+
        tst.b   (a1)+
        jmp     loop2(pc,d6.w)

oe3:    tst.w   (a0)+
        tst.b   (a1)+
        jmp     loop3(pc,d6.w)

eo0:    tst.b   (a0)+
        cmpm.w  (a0)+,(a1)+
        jmp     loop3(pc,d6.w)

eo1:    tst.b   (a0)+
        jmp     loop2(pc,d6.w)

eo2:    tst.b   (a0)+
        jmp     loop3(pc,d6.w)

eo3:    tst.b   (a0)+
        cmpm.w  (a0)+,(a1)+
        jmp     loop2(pc,d6.w)

loop0:  our_rept        8,<cmpm.l (a0)+,(a1)+>
        dbf     d4,loop0
        bra.s   rowend

loop1:  our_rept        8,<cmpm.l (a0)+,(a1)+>
        dbf     d4,loop1
        cmpm.b  (a0)+,(a1)+
        bra.s   rowend

loop2:  our_rept        8,<cmpm.l (a0)+,(a1)+>
        dbf     d4,loop2
        tst.b   (a1)+
        bra.s   rowend

loop3:  our_rept        8,<cmpm.l (a0)+,(a1)+>
        dbf     d4,loop3
        cmpm.b  (a0)+,(a1)+
        tst.b   (a1)+

rowend: dbf     d2,nextrow

* done with strip, write out rest of bins
        move.w  arg55w(a6),d1           * # of bins to write
        tst.w   arg45l(a6)
        bmi     .32

* tan(theta) >= 0 case
        addq.l  #1,a5
```

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```
        bra.s   .41
.40:    move.l  (a3)+,d0
        add.l   d0,(a4)+
        tst.b   (a5)+
        bne.s   .41
        lea     -254*4(a3),a3
.41:    dbf     d1,.40
        bra.s   .50

* tan(theta) < 0 case
.32:    sub.l   #M_load,a0
        bra.s   .31
.30:    move.l  -(a3),d0
        add.l   d0,(a4)+
        tst.b   -(a0)
        bne.s   .31
        lea     254*4(a3),a3
.31:    dbf     d1,.30

.50:    movem.l (sp)+,rsl
        unlk    a6
        rts

_project_table:
        dc.l    ee0,ee1,ee2,ee3
        dc.l    eo0,eo1,eo2,eo3
        dc.l    oe0,oe1,oe2,oe3
        dc.l    oo0,oo1,oo2,oo3

model_codes:
        dc.b    $00,$01,$02,$03,$04,$05,$06,$07,$08,$09,$0A,$0B,$0C,$0D,$0E,$0F
        dc.b    $10,$11,$12,$13,$14,$15,$16,$17,$18,$19,$1A,$1B,$1C,$1D,$1E,$1F
        dc.b    $20,$21,$22,$23,$24,$25,$26,$27,$28,$29,$2A,$2B,$2C,$2D,$2E,$2F
        dc.b    $30,$31,$32,$33,$34,$35,$36,$37,$38,$39,$3A,$3B,$3C,$3D,$3E,$3F
        dc.b    $40,$41,$42,$43,$44,$45,$46,$47,$48,$49,$4A,$4B,$4C,$4D,$4E,$4F
        dc.b    $50,$51,$52,$53,$54,$55,$56,$57,$58,$59,$5A,$5B,$5C,$5D,$5E,$5F
        dc.b    $60,$61,$62,$63,$64,$65,$66,$67,$68,$69,$6A,$6B,$6C,$6D,$6E,$6F
        dc.b    $70,$71,$72,$73,$74,$75,$76,$77,$78,$79,$7A,$7B,$7C,$7D,$7E,$7F
        dc.b    $80,$81,$82,$83,$84,$85,$86,$87,$88,$89,$8A,$8B,$8C,$8D,$8E,$8F
        dc.b    $90,$91,$92,$93,$94,$95,$96,$97,$98,$99,$9A,$9B,$9C,$9D,$9E,$9F
        dc.b    $A0,$A1,$A2,$A3,$A4,$A5,$A6,$A7,$A8,$A9,$AA,$AB,$AC,$AD,$AE,$AF
        dc.b    $B0,$B1,$B2,$B3,$B4,$B5,$B6,$B7,$B8,$B9,$BA,$BB,$BC,$BD,$BE,$BF
        dc.b    $C0,$C1,$C2,$C3,$C4,$C5,$C6,$C7,$C8,$C9,$CA,$CB,$CC,$CD,$CE,$CF
        dc.b    $D0,$D1,$D2,$D3,$D4,$D5,$D6,$D7,$D8,$D9,$DA,$DB,$DC,$DD,$DE,$DF
        dc.b    $E0,$E1,$E2,$E3,$E4,$E5,$E6,$E7,$E8,$E9,$EA,$EB,$EC,$ED,$EE,$EF
        dc.b    $F0,$F1,$F2,$F3,$F4,$F5,$F6,$F7,$F8,$F9,$FA,$FB,$FC,$FD
        dc.b    $00,$01,$02,$03,$04,$05,$06,$07,$08,$09,$0A,$0B,$0C,$0D,$0E,$0F
        dc.b    $10,$11,$12,$13,$14,$15,$16,$17,$18,$19,$1A,$1B,$1C,$1D,$1E,$1F
        dc.b    $20,$21,$22,$23,$24,$25,$26,$27,$28,$29,$2A,$2B,$2C,$2D,$2E,$2F
        dc.b    $30,$31,$32,$33,$34,$35,$36,$37,$38,$39,$3A,$3B,$3C,$3D,$3E,$3F
```

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```
        dc.b    $40,$41,$42,$43,$44,$45,$46,$47,$48,$49,$4A,$4B,$4C,$4D,$4E,$4F
        dc.b    $50,$51,$52,$53,$54,$55,$56,$57,$58,$59,$5A,$5B,$5C,$5D,$5E,$5F
        dc.b    $60,$61,$62,$63,$64,$65,$66,$67,$68,$69,$6A,$6B,$6C,$6D,$6E,$6F
        dc.b    $70,$71,$72,$73,$74,$75,$76,$77,$78,$79,$7A,$7B,$7C,$7D,$7E,$7F
        dc.b    $80,$81,$82,$83,$84,$85,$86,$87,$88,$89,$8A,$8B,$8C,$8D,$8E,$8F
        dc.b    $90,$91,$92,$93,$94,$95,$96,$97,$98,$99,$9A,$9B,$9C,$9D,$9E,$9F
        dc.b    $A0,$A1,$A2,$A3,$A4,$A5,$A6,$A7,$A8,$A9,$AA,$AB,$AC,$AD,$AE,$AF
        dc.b    $B0,$B1,$B2,$B3,$B4,$B5,$B6,$B7,$B8,$B9,$BA,$BB,$BC,$BD,$BE,$BF
        dc.b    $C0,$C1,$C2,$C3,$C4,$C5,$C6,$C7,$C8,$C9,$CA,$CB,$CC,$CD,$CE,$CF
        dc.b    $D0,$D1,$D2,$D3,$D4,$D5,$D6,$D7,$D8,$D9,$DA,$DB,$DC,$DD,$DE,$DF
        dc.b    $E0,$E1,$E2,$E3,$E4,$E5,$E6,$E7,$E8,$E9,$EA,$EB,$EC,$ED,$EE,$EF
        dc.b    $F0,$F1,$F2,$F3,$F4,$F5,$F6,$F7,$F8,$F9,$FA,$FB,$FC,$FD

        endc
```

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```
*       Copyright (c) $Data: 91/11/21 16:29:16 $
*       Cognex Corporation, Needham, MA 02194
*       $Source: /nfs/lex/products/x000/src/cpro/vp_image_xhist.m68,v $
*       $Revision: 1.13 $
*       $Locker:  $
        plen    52,2,0

        ;**************
        ;            *
        ; X Histogram *
        ;            *
        ;**************

* For now, the same code runs on VM8 and VM10.  The optimal code on
* VM10 should use the A-register mode.

        nolist
        include section.i68
        include which_bd.i68
        ifnm C_BOARD-C_UNIX
        include callc.i68
        include argoff.i68
        include vcp.i68
        include image_xhist.h68
        list

        our_section data

        DC      '$Source: /nfs/lax/products/x000/src/cpro/vp_image_xhist.m68,v $'
        DC      '$Revision: 1.13 $'

        xdef    _image_xhist
        xref    _E_clear,_write_zhist,_make_hist,_cct_error
        xref    _grab_vm7s,_vm7s_inuse

* histogram *image_xhist (image, x_hist, z_hist)
*   cip_buffer *image;
*   histogram *y_hist, **z_hist;
*
* Compute and return a X (sum of columns) histogram from a FAST8 image.
* If requested, also return a Z histogram of the image. If the x_hist
* argument is 0, a new histogram will be allocated. If z_hist is 0, no
* Z histogram will be returned. If z_hist points to a 0, a new one will
* be allocated and returned to *z_hist. Otherwise use **z_hist.
*
* Stack frame:

        offset  0
        ds.1    6+4
regs    equ     -*              * register save area
```

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```
        ds.l    1
bins    equ     .*                      * ->current position in xhist bins
        ds.l    1
rat     equ     .*                      * copy of image->rat
        ds.l    1
counter equ     .*                      * precomputed inner loop counters
        ds.w    1
odd     equ     .*                      * 1 if image has odd alignment
        ds.b    1+254+8
        ds.w    0
model   equ     .*                      * model codes (must be highest on stack)

* Register save list

rsl     reg     d2-d7/a2-a5

        our_section     fast

* Register use during initialization:
*
*       d3      "ODD"
*       d4      image-> height
*       d5      image-> x_offset
*       d6      image->width
*
*       a3      -> image
*       a5      image-> rat
*       a6      normal link pointer for argument references

_image_xhist:

        link    a6,#model
        movem.l rsl,regs(a6)

        move.l  arg1$1(a6),a3                   * a3 -> image
        move.w  cip_buffer$flags(a3),d0
        and.w   #CIP_FLAGS_FAST8,d0
        bne.s   .1
        callc   cct_error,4,#CIP_ERR_PELDEPTH
.1:     move.l  cip_buffer$rat(a3),a5           * a5 -> RAT
        move.l  a5,rat(a6)
        moveq   #0,d6                           *
        move.w  cip_buffer$width(a3),d6         * d6 = image-> width
        moveq   #0,d4                           *
        move.w  cip_buffer$height(a3),d4        * d4 = image-> height
        moveq   #0,d5                           *
        move.w  cip_buffer$x_offset(a3),d5      * d5 = image-> x_offset
        move.l  (a5),d3                         *
        add.w   d5,d3                           *
```

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```
        and.l   #1,d3                          * d3 = 1/0 : odd/even alignment
        move.w  d3,odd(a6)
        add.l   #1_load,d5                     * vm7s control bits
        sub.l   d3,d5                          * word-align rat[n]+d5

* Get X histogram, allocate if necessary, check for sufficient bins,
* set histogram range, get pointer to bins.

        move.l  arg2$1(a6),d0
        bne.s   .220
        callc   make_hist,4,d6
.220:   move.l  d0,a0
        move.l  d0,arg2$1(a6)
        chk     histogram$bins(a0),d6
        move.w  d6,histogram$range(a0)
        move.w  d4,d0
        mulu    d6,d0                  * Number of pixels.
        move.l  d0,histogram$n(a0)     *
xvalid  equ     1<<bn_valid+1<<n_valid+1<<m0_valid
        move.l  #xvalid,histogram$valid(a0)
        clr.l   histogram$mom0(a0)
        lea     histogram$(a0),a0      * -> bins.
        move.l  a0,bins(a6)
        tst.l   d0                     * 0 width or height model ?
        bne.s   .4
        move.l  d6,d3
        bra     writex

* Compute model codes. Registers:
*
*       d0      model pel
*       d1      bin counter
*       d3      "odd", then slice width
*       d4      image-> height
*       d6      image-> width
*
*       a0      -> model array

* model for even image: codes 0 - 253, 8 don't cares
* model for odd image: 1 dc, codes 0 - 253, 8 dc's
* If the image is < 254 wide, a smaller model is written to the stack.
* A wide image is processed in 254 pel slices.  For each slice 256 pels
* are fetched, but two correspond to a don't care.  For the last slice of
* the image, up to 7 bytes past the end of row are fetched, since the
* pels are fetched 2 longs at a time.  For this reason, write out 8 dc pels
* into the model before doing the last slice.

.4:     lea     model(a6),a0           * a0 -> model array.
        tst.b   d3
        beq     .5
```

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```
        move.b  #-1,(a0)+
.5:     move.l  d6,d3
        cmp.w   #254,d3          * does the image fit in 1 slice
        ble     .6
        move.w  #254,d3          * no, the slice is 254 wide
        move.w  d4,d1            * precompute inner loop counter
        subq.w  #1,d1
        lsr.w   #2,d1
        swap    d1                     * d1$h = ( height - 1 )/4
        move.w  #31,d1                 * d1$l = (pels+7)/8 - 1
        move.l  d1,counter(a6)
.6:     move.w  d3,d2
        subq.w  #1,d2
        moveq   #0,d0
.7:     move.b  d0,(a0)+
        addq.b  #1,d0
        dbra    d2,.7
        moveq   #6,d2
        moveq   #-1,d0
.8:     move.b  d0,(a0)+
        dbra    d2,.8

* Register use for input and output loops:
*
*       d0      hi word: 4-rows-at-a-time counter
*               lo word: 8-column blocks counter
*       d1      initial counter values for d0
*       d2      Jump table offset for processing remainder rows.
*       d3      slice width
*       d4      image height
*       d5      slice offset - DDD + I_load
*       d6      image width
*       d7      model pointer + M_load
*       a0      1st row pointer
*       a1      2nd row pointer
*       a2      3rd row pointer
*       a3      4th row pointer
*       a4      indexes thru model
*       a5      image-> ras
*
* Rows will be processed 4 at a time. The remaining rows are done first,
* an index into a jump table to accomplish this is computed in d2.

        move.w  d4,d2
        subq.w  #1,d2
        and.w   #3,d2
        lsl.w   #2,d2                  * d2 = ( ( height - 1 ) % 4 ) * 4

        lea     model(a5),a4           * Init model pointer
        add.l   #M_load,a4             *
```

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```
        move.l  a4,d7
        jsr     _grab_vm7s

slice:  move.l  counter(a6),d1
        cmp.w   d6,d3               * is this the last slice?
        bne     .10
        lea     model(a6),a0        * yes, pad the end with don't cares
        add.w   odd(a6),a0
        add.w   d3,a0
        moveq   #-1,d1
        moveq   #6,d0
.9:     move.b  d1,(a0)+
        dbra    d0,.9
        move.w  d4,d1               * and recompute counter
        subq.w  #1,d1
        lsr.w   #2,d1
        swap    d1                  * d1$h - ( height - 1 )/4
        move.w  d3,d1
        add.w   odd(a6),d1
        subq.w  #1,d1
        asr.w   #3,d1               * d1$l - (pels+7)/8 - 1
.10:    move.l  rat(a6),a5
        move.l  (a5)+,a0            * Fetch first row pointer
        add.l   d5,a0               * Add x_offset to row pointer
        move.l  d7,a4               * init model pointer
        move.l  d1,d0               * Init row and block counters.
        move.l  etable(pc,d2.w),a1  * Jump into the computed ESP.
        jmp     (a1)                *

* Entry point table for the remaining rows.

etable: dc.l    .110,.120,.130,.140

* Do one leftover row.

.110:   lsr.w   #1,d0               * The loop is expanded,
        bcc.s   .112                * so reduce the count.

.111:   cmpm.l  (a4)+,(a0)+         * 4 model, 4 pixels
        cmpm.l  (a4)+,(a0)+         * 4 model, 4 pixels.
.112:   cmpm.l  (a4)+,(a0)+         *
        cmpm.l  (a4)+,(a0)+         *
        dbf     d0,.111             *

        bra     .144                * done, now do 4 at a time

* Do two leftover rows.

.120:   move.l  (a5)+,a1            * Fetch second row pointer
        add.l   d5,a1               * Add x_offset to row pointer
```

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```
        lsr.w   #1,d0               * The loop is expanded, so
        bcc.s   .122                * reduce the count.

.121:   cmpm.l  (a4)+,(a0)+         * 4 model, 4 pixels
        cmpm.l  (a4)+,(a0)+         * 4 model, 4 pixels.
        cmpm.l  (a1)+,(a1)+         * 8 pixels from row 2

.122:   cmpm.l  (a4)+,(a0)+         *
        cmpm.l  (a4)+,(a0)+         * Next chunk. Note that the next
        cmpm.l  (a1)+,(a1)+         * model codes are being loaded.
        dbf     d0,.121             *

        bra.s   .144                * done. now do 4 at a time

* Do three leftover rows.

.130:   move.l  (a5)+,a1            * Fetch third row pointer.
        add.l   d5,a1               * Add x_offset to row pointer

        move.l  (a5)+,a2            * Same for third row pointer
        add.l   d5,a2               *

        lsr.w   #1,d0               * The loop is expanded,
        bcc.s   .132                * so reduce the count.

.131:   cmpm.l  (a4)+,(a0)+         * 4 model, 4 pixels
        cmpm.l  (a4)+,(a0)+         * 4 model, 4 pixels
        cmpm.l  (a1)+,(a1)+         * 8 pixels from row 2
        cmpm.l  (a2)+,(a2)+         * 8 pixels from row 3

.132:   cmpm.l  (a4)+,(a0)+         *
        cmpm.l  (a4)+,(a0)+         * Next chunk.
        cmpm.l  (a1)+,(a1)+         *
        cmpm.l  (a2)+,(a2)+         *
        dbf     d0,.131             *

        bra.s   .144                * done, now do 4 at a time

* Do next four rows

.143:   move.l  d7,a4               * init model pointer
        swap    d0                  * save row count
        move.w  d1,d0               * init block counter

        move.l  (a5)+,a0            * Make the first row pointer
        add.l   d5,a0               *

* Entry point for no leftover rows
```

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```
.140:   move.l  (a5)+,a1                * Make the second row pointer
        add.l   d5,a1                   *

        move.l  (a5)+,a2                * Make the third row pointer
        add.l   d5,a2                   *

        move.l  (a5)+,a3                * Make the fourth row pointer
        add.l   d5,a3                   *

        lsr.w   #1,d0                   * Loop is expanded,
        bcc.s   .142                    * reduce the loop count.

.141:   cmpm.l  (a4)+,(a0)+             * 4 model, 4 row 1 pixels
        cmpm.l  (a4)+,(a0)+             * 4 model, 4 row 1 pixels
        cmpm.l  (a1)+,(a1)+             * 8 row 2 pixels
        cmpm.l  (a2)+,(a2)+             * 8 row 3 pixels
        cmpm.l  (a3)+,(a3)+             * 8 row 4 pixels

.142:   cmpm.l  (a4)+,(a0)+             * Reload the model fifo, do
        cmpm.l  (a4)+,(a0)+             * the next chunk.
        cmpm.l  (a1)+,(a1)+             *
        cmpm.l  (a2)+,(a2)+             *
        cmpm.l  (a3)+,(a3)+             *
        dbf     d0,.141

.144:   swap    d0                      * done, get row counter
        dbf     d0,.143                 * 4 more rows?

* Register use during histogram writing.
*
*       d0      loop counter
*       d1      Sum of pixels
*       d3      slice width
*
*       a0      temp
*       a2      -> xhist bins, then ->xhist struct
*       a3      -> vm7/s C[0]
*
writex: move.l  #C_array,a3             * a3-> C array.

* Write the x_hist bins, and compute the sum of all pixels

        move.w  d3,d0
        moveq   #0,d1
        move.l  bins(a6),a2
        bra.s   .201

.200:   move.l  (a3)+,a0                * Get the sum of a column.
        move.l  a0,(a2)+                * Write it to x_hist.
        add.l   a0,d1                   * Keep a total of all pixels.
```

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```
.201:   dbf     d0,.200                         *
        move.l  a2,bins(a6)
        move.l  arg2$1(a6),a2
        add.l   d1,histogram$mom0(a2)

* go to next slice

        sub.l   d3,d6                   * compute width left to go
        add.l   d3,d5                   * add slice just done to offset
        cmp.l   d6,d3                   * more than 1 slice remaining?
        blt     slice
        move.l  d6,d3                   * no - do possibly smaller last slice
        bne     slice                   * unless we're all done

* Write z_hist if requested.

        move.l  arg3$1(a6),d0           * Branch if z_hist not requested.
        beq.s   .210

        move.l  d0,a0
        callc   write_zhist,44,(a0),histogram$n(a2)
        move.l  d0,a1                   * Since mom1 wasn't in C[0] as expected
        move.l  histogram$mom0(a2),histogram$mom1l(a1)  * by write_hist, store
        clr.l   histogram$mom1h(a1)
        move.l  d0,(a0)                 *  correct value and return z_hist
        bra.s   .211                    *

.210:   jsr     _E_clear                * not requested, clear E
.211:   clr.b   _vm7s_inuse
        move.l  arg2$1(a6),d0           * Return x_hist.
        movem.l regs(a6),rsl            *
        unlk    a6                      *
        rts

        endc
```

I claim:

1. An apparatus for identifying a linear pattern, having an expected radius less than or equal to a value r, in an image signal, I, said apparatus comprising:

A. projection means for generating a projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of said linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along said axis,

B. mirror symmetry filter means, coupled with said projection means, responsive to said radius and said projection signal for filtering that projection signal to generate a mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

wherein said mirror symmetry filter means includes means for filtering said projection signal P to generate two mirror symmetry signals, S_1 and S_2, wherein each signal S_1, S_2 is representative of the degree of symmetry of the projection signal P about each point therein, and wherein each signal S_1, S_2 is out of phase with the other,

C. notch detection means, coupled with said mirror symmetry filter means, for operating on said mirror symmetry signal with a selected mask to generate a peak location signal emphasizing a peak in said mirror symmetry signal corresponding to a location of a center of said linear pattern, and

D. peak locating means, coupled with said notch detection means, for identifying a peak in said peak location signal, and for estimating from a location of that peak a location of a center of said linear pattern.

2. An apparatus for identifying a cross-hair comprising a plurality of intersecting linear patterns, having expected radii less than or equal to a value r, in an image signal, I, said apparatus comprising:

A. projection means for a generating, for each of said linear patterns, a corresponding projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of that linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along the respective axis,

B. mirror symmetry filter means, coupled with said projection means, and responsive to said radius and each said projection signal, for filtering that projection signal to generate a corresponding mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

wherein said mirror symmetry filter means includes means for filtering said projection signal P to generate two mirror symmetry signals, S_1 and S_2, wherein each signal S_1, S_2 is representative of the degree of symmetry of the projection signal P about each point therein, and wherein each signal S_1, S_2 is out of phase with the other,

C. notch detection means, coupled with said mirror symmetry filter means, for operating on each said mirror symmetry signal with a selected mask to generate a corresponding peak location signal emphasizing a peak in each said mirror symmetry signal corresponding to a location of a center of the corresponding linear pattern,

D. peak locating means, coupled with said notch detection means, for identifying a peak in each said peak location signal, and for estimating from a location of that peak a location of a center of the corresponding linear pattern, and

E. center point locating means, coupled with said peak locating means, for determining the center of said cross-hair pattern to lie at an intersection of the estimated locations of said linear patterns.

3. An apparatus according to any of claim 1 and 2, wherein said mirror symmetry filter means includes

A. means for filtering a projection signal to generate said mirror symmetry signal, S_1, comprising elements S_1i, wherein each element S_1i has a value determined in accord with the mathematical function

$$S_{1i} = \sum_{a=1}^{r} |P_{i+a} - P_{i-a}|$$

B. means for filtering a projection signal to generate said mirror symmetry signal, S_2, comprising elements S_2i, wherein each element S_2i has a value determined in accord with the mathematical function

$$S_{2i} = \sum_{a=1}^{r-1} |P_{i+a} - P_{i-a}|.$$

4. An apparatus according to claim 3, wherein

A. said notch detection means includes means for operating on each said mirror symmetry signal, S_1, S_2, to generate corresponding peak location signals, L_1, L_2,

B. said peak locating means includes

i) means for identifying in said peak location signal L_1 a position and amplitude of a most significant peak,

ii) means for identifying positions and amplitudes of a neighboring point on each side of a most significant peak in said peak location signal L_2, and

iii) means for estimating from the positions and amplitudes of those neighboring points a location of the center of said linear pattern.

5. An apparatus for identifying a linear pattern, having an expected radius less than or equal to a value r, in an image signal, I, said apparatus comprising:

A. projection means for generating a projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of said linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along said axis,

B. mirror symmetry filter means, coupled with said projection means, responsive to said radius and said projection signal for filtering that projection signal to generate a mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

C. notch detection means, coupled with said mirror symmetry filter means, for operating on said mirror symmetry signal with a selected mask to generate a peak location signal emphasizing a peak in said mirror symmetry signal corresponding to a location of a center of said linear pattern,

wherein said notch detection means includes means for operating on said mirror symmetry signal S with a selected mask in accord with the mathematical function

$$L_i = \min\left(\frac{1}{p}\sum_{j=0}^{p-1} S_{i+j}, \frac{1}{p}\sum_{j=p+2z+n}^{2p+2z+n-1} S_{i+j}\right) - \frac{1}{n}\sum_{j=p+z}^{p+z+n-1} S_{i+j}$$

where N, P and Z are elements of said mask, each of respective lengths n, p and z, and

D. peak locating means, coupled with said notch detection means, for identifying a peak in said peak location signal, and for estimating from a location of that peak a location of a center of said linear pattern.

6. An apparatus for identifying a cross-hair comprising a plurality of intersecting linear patterns, having expected radii less than or equal to a value r, in an image signal, I, said apparatus comprising:

A. projection means for a generating, for each of said linear patterns, a corresponding projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of that linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along the respective axis,

B. mirror symmetry filter means, coupled with said projection means, and responsive to said radius and each said projection signal, for filtering that projection signal to generate a corresponding mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

C. notch detection means, coupled with said mirror symmetry filter means, for operating on each said mirror symmetry signal with a selected mask to generate a corresponding peak location signal emphasizing a peak in each said mirror symmetry signal corresponding to a location of a center of the corresponding linear pattern,

wherein said notch detection means includes means for operating on said mirror symmetry signal S with a selected mask in accord with the mathematical function

$$L_i = \min\left(\frac{1}{p}\sum_{j=0}^{p-1} S_{i+j}, \frac{1}{p}\sum_{j=p+2z+n}^{2p+2z+n-1} S_{i+j}\right) - \frac{1}{n}\sum_{j=p+z}^{p+z+n-1} S_{i+j}$$

where N, P and Z are elements of said mask, each of respective lengths n, p and z, and

D. peak locating means, coupled with said notch detection means, for identifying a peak in each said peak location signal, and for estimating from a location of that peak a location of a center of the corresponding linear pattern, and

E. center point locating means, coupled with said peak locating means, for determining the center of said cross-hair pattern to lie at an intersection of the estimated locations of said linear patterns.

7. An apparatus according to any of claims **5** and **6**, wherein said notch detection means includes means for generating said peak location signal L by operating on said mirror symmetry signal with a mask signal, M, said mask signal having an amplitude that peaks toward the center.

8. An apparatus according to claim **7**, wherein said notch detection means includes means for generating said peak location signal L by operating on said mirror symmetry signal with a mask signal, M, said mask signal having elements M_k, where k is between 1 and 7, and where those elements have respective values ½, ½, 0, −1, 0, ½, ½.

9. A method for identifying a linear pattern having an expected radius less than or equal to a value r, in an image signal, I, said method comprising:

A. a projection step for generating a projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of said linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along said axis,

B. a mirror symmetry filter step responsive to said radius and said projection signal for filtering that projection signal to generate a mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

wherein said mirror symmetry filter step includes a step for filtering said projection signal P to generate two mirror symmetry signals, S_1 and S_2, wherein each signal S_1, S_2 is representative of the degree of symmetry of the projection signal P about each point therein, and wherein each signal S_1, S_2 is out of phase with the other,

C. a notch detection step for operating on said mirror symmetry signal with a selected mask to generate a peak location signal emphasizing a peak in said mirror symmetry signal corresponding to a location of a center of said linear pattern, and

D. a peak locating step for identifying a peak in said peak location signal, and for estimating from a location of that peak a location of a center of said linear pattern.

10. A method for identifying a cross-hair comprising a plurality of intersecting linear patterns, having expected radii less than or equal to a value r, in an image signal, I, said method comprising:

A. a projection step for a generating, for each of said linear patterns, a corresponding projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of that linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along the respective axis,

B. a mirror symmetry filter step for responding to said radius and each said projection signal for filtering that projection signal to generate a corresponding mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

wherein said mirror symmetry filter step includes a step for filtering said projection signal P to generate two mirror symmetry signals, S_1 and S_2, wherein each signal S_1, S_2 is representative of the degree of symmetry of the projection signal P about each point therein, and wherein each signal S_1, S_2 is out of phase with the other,

C. a notch detection step for operating on each said mirror symmetry signal with a selected mask to generate a corresponding peak location signal emphasizing a peak in each said mirror symmetry signal corresponding to a location of a center of the corresponding linear pattern,

D. a peak locating step for identifying a peak in each said peak location signal, and for estimating from a location of that peak a location of a center of the corresponding linear pattern, and

E. a center point locating step for determining the center of said cross-hair pattern to lie at an intersection of the estimated locations of said linear patterns.

11. A method according to any of claims **9** and **10**, wherein said mirror symmetry filter step includes

A. a step for filtering a projection signal to generate said mirror symmetry signal, S_1, comprising elements S_1i, wherein each element S_1i has a value determined in accord with the mathematical function

$$Si = \sum_{a=1}^{r} |Pi + a - Pi - a|$$

B. a step for filtering a projection signal to generate said mirror symmetry signal, S_2, comprising elements S_2i, wherein each element S_1i has a value determined in accord with the mathematical function

$$Si = \sum_{a=0}^{r-1} |Pi + a - Pi - a - 1|,$$

12. A method according to claim 11, wherein

A. said notch detection step includes a step for operating on each said mirror symmetry signal, S_1, S_2, to generate corresponding peak location signals, L_1, L_2,

B. said peak locating step includes

i) a step for identifying in said peak location signal L_1 a position and amplitude of a most significant peak,

ii) means for identifying positions and amplitudes of a neighboring points on each side of a most significant peak in said peak location signal L_2, and

iii) means for estimating, from the positions and amplitudes of those neighboring points a location of the center of said linear pattern.

13. A method for identifying a linear pattern, having an expected radius less than or equal to a value r, in an image signal, I, said method comprising:

A. a projection step for generating a projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of said linear pattern, where said projection signal, P, is comprised of elements P_i, wherein i is an integer between 1 and a length of said image signal along said axis,

B. a mirror symmetry filter step responsive to said radius and said projection signal for filtering that projection signal to generate a mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

C. a notch detection step for operating on said mirror symmetry signal with a selected mask to generate a peak location signal emphasizing a peak in said mirror symmetry signal corresponding to a location of a center of said linear pattern,

wherein said notch detection means includes means for operating on said mirror symmetry signal S with a selected mask in accord with the mathematical function

$$L_i = \min\left(\frac{1}{p}\sum_{j=0}^{p-1} S_{i+j}, \frac{1}{p}\sum_{j=p+2z+n}^{2p+2z+n-1} S_{i+j}\right) - \frac{1}{n}\sum_{j=p+z}^{p+z+n-1} S_{i+j}$$

where N, P and Z are elements of said mask, each of respective lengths n, p and z, and

D. a peak locating step for identifying a peak in said peak location signal, and for estimating from a location of that peak a location of a center of said linear pattern.

14. A method for identifying a cross-hair comprising a plurality of intersecting linear patterns, having expected radii less than or equal to a value r, in an image signal, I, said method comprising:

A. a projection step for a generating, for each of said linear patterns, a corresponding projection signal, P, representative of a projection of said image signal along an axis substantially aligned with an expected orientation of that linear pattern, where said projection signal, P, is comprised of elements P_i, where i is an integer between 1 and a length of said image signal along the respective axis,

B. a mirror symmetry filter step for responding to said radius and each said projection signal for filtering that projection signal to generate a corresponding mirror symmetry signal, S, representative of the degree of symmetry of the projection signal P about each point therein,

C. a notch detection step for operating on each said mirror symmetry signal with a selected mask to generate a corresponding peak location signal emphasizing a peak in each said mirror symmetry signal corresponding to a location of a center of the corresponding linear pattern,

wherein said notch detection means includes means for operating on said mirror symmetry signal S with a selected mask in accord with the mathematical function

$$L_i = \min\left(\frac{1}{p}\sum_{j=0}^{p-1} S_{i+j}, \frac{1}{p}\sum_{j=p+2z+n}^{2p+2z+n-1} S_{i+j}\right) - \frac{1}{n}\sum_{j=p+z}^{p+z+n-1} S_{i+j}$$

where N, P and Z are elements of said mask, each of respective lengths n, p and z, and

D. a peak locating step for identifying a peak in each said peak location signal, and for estimating from a location of that peak a location of a center of the corresponding linear pattern, and

E. a center point locating step for determining the center of said cross-hair pattern to lie at an intersection of the estimated locations of said linear patterns.

15. A method according to any of claims 13 and 14, wherein said notch detection step includes a step for generating said peak location signal L by operating on said mirror symmetry signal with a mask signal, M, said mask signal having an amplitude that peaks toward the center.

16. A method according to claim 15, wherein said notch detection step includes a step for generating said peak location signal L by operating on said mirror symmetry signal with a mask signal, M, said mask signal having elements M_k, where k is between 1 and 6, and where those elements have respective values ½, ½, 0, −1, 0, ½, ½.

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